NBS TECHNICAL NOTE 1097

U.S. DEPARTMENT OF COMMERCE / National Bureau of Standards

Interactive FORTRAN Programs for Micro Computers to Calculate the Thermophysical Properties of Twelve Fluids [MIPROPS]

Robert D. McCarty

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[3] Located at Boulder, CO, with some elements at Gaithersburg, MD.

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INTERACTIVE FORTRAN PROGRAMS FOR MICRO COMPUTERS TO CALCULATE THE THERMOPHYSICAL PROPERTIES OF TWELVE FLUIDS [MIPROPS]

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The thermophysical and transport properties of selected fluids have been programmed in FORTRAN 77 which is available for micro computers. The input variables are any two of P, ρ, T (pressure, density, and temperature) in the single phase regions, and either P or T for the saturated liquid or vapor states. The output is pressure, density, temperature, internal energy, enthalpy, entropy, specific heat capacities (C_p and C_v), speed of sound and, in most cases, viscosity, thermal conductivity and dielectric constant.

The fluids included are: helium, hydrogen, nitrogen, oxygen, argon, nitrogen trifluoride, methane, ethylene, ethane, propane, iso- and normal butane. The programs give properties in both the liquid and vapor states over a wide range of temperature and pressure. Copies of the program may be obtained from the Office of Standard Reference Data, Room A320, Physics Building, National Bureau of Standards, Gaithersburg, MD 20899.

Key words: argon; computer programs; density; dielectric constant; enthalpy; entropy; equation of state; ethane, ethylene; heat capacity; helium; hydrogen; internal energy; isobutane; methane; nitrogen; nitrogen trifluoride; normal butane; oxygen; pressure; speed of sound; temperature; thermal conductivity; viscosity.

1. Introduction

Recent technological advances in the field of personal computers have made it possible and practical to run large FORTRAN programs on these machines. The programs presented here will run satisfactorily on a wide variety of personal computers on the market today.

The programs are a direct translation of those developed by Younglove [1,2], with five additional fluids added [3]. The separate program for helium originally appeared in NBS Technical Note 1025 by McCarty [4] and was, in turn, derived from an earlier evaluation of helium data [5]. The programs in the above-mentioned documents were written as interactive FORTRAN IV programs intended to run on large main frames. The programs presented here are translations of the originals to FORTRAN 77 adapted to personal computers and reproduce the calculations of the originals exactly.

All of the fluids except helium utilize the same mathematical model of the equation of state which was originally proposed by Jacobsen [6]. The model for the helium thermodynamic surface is of a different form, and a separate program was necessary for that fluid. The mathematical model of the transport properties of the fluids which have been added to those from NBS Technical Note 1048, has been improved and new routines are utilized for those fluids.

The programs produce the transport properties for all of the fluids except hydrogen, nitrogen trifluoride, ethylene, ethane and propane. The dielectric constant is also provided for all of the fluids except argon, ethylene and nitrogen trifluoride.

There is a section devoted to each fluid in Appendix A and the reader is referred to those sections for further information on an individual fluid. Listings of the source code and sample calculations may be found in Appendices B and C.

2. Uncertainties of the Calculated Properties

When calculating thermodynamic properties from an empirical equation of state, one should be aware of certain problem areas of the thermodynamic surface. In the critical region ($\rho_c \pm 0.2\ \rho_c$ and $T_c \pm 0.05\ T_c$), the calculated density may be in error by several percent, while the calculated pressure or temperature will not be as inaccurate. Values of specific heat capacity and thermal conductivity in the critical region become very large and no realistic estimate of the uncertainty may be made. Saturation boundaries, gas-liquid, and liquid-solid are potential areas of large uncertainties for derived thermodynamic properties, especially heat capacities. In the compressed liquid region, calculated pressures will have an uncertainty of several percent. This is a consequence of the nature of the surface and is in no way the fault of the equation of state.

In each of the sections on the individual fluids, uncertainty estimates are given for that particular fluid. These estimates do not reflect the potential large uncertainties of the problem areas outlined above.

3. Computer Routines

The thermophysical properties produced by the computer programs listed in Appendix C are all calculated using a mathematical model of the equation of state of the fluid and classical thermodynamic relationships. The reader who is interested in the thermodynamics and mathematics of the problem is referred to McCarty [7].

In general eleven or twelve significant figures are needed in the property calculations to prevent round off errors. Sample calculations for each fluid are given in Appenidx A for the purpose of checking the performance of the programs on individual computers.

Upper and lower temperature and pressure limits for each fluid have been installed in the programs according to the range of validity as claimed by the original source document. All of the functions reduce to the ideal gas in the limit of zero pressure, but because of the very large exponents in some of the terms, the iterative solution for density fails at very low pressures. Because the models are empirical and cannot be trusted to give even reasonable results outside their ranges of pressure and temperature, the user is cautioned not to change the pressure or temperature limits originally set in the programs.

4. Acknowledgments

The author wishes to acknowledge the support of NASA, without which this work would not have been possible, and in particular the support and encouragement of Dr. Timothy Cleghorn at the Johnson Space Center.

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Appendix A

Description of Individual Fluids

[PARAHYDROGEN]

The source of the hydrogen equation of state is NBSIR 75-814 by Roder and McCarty [8] and Stewart [9].

Estimated Uncertainties (%)

Property	Liquid Below T_c	Gas Below T_c	Fluid Above T_c
Pressure	5.0	0.25	0.20
Density	0.1	0.25	0.20
Temperature	0.1	0.25	0.20
Enthapy & Internal Energy	1.0	3.0	5.10
Entropy	1.0	1.0	1.0
C_p and C_v	3.0	2.0	3.0
Speed of Sound	2.0	1.0	1.0

Fixed Points

	Pressure, MPa	Density, M/L	Temperature, K
Critical Point	1.2838	15.556	32.938
Triple Point Liquid	0.00743	0.06323	13.80
Triple Point Vapor	0.00743	38.2143	

Temperature Range 13.8 to 400 K

Pressure Range 0 to 120 MPa

Sample Calculations

```
THE TEMPERATURE RANGE FOR HYDROGEN IS 13.8 TO 400 K
(-434.8 TO 260 F) WITH PRESSURES TO 120 MPA (17404 PSIA)
FOR ENGINEERING UNITS ENTER "0", FOR METRIC ENTER "1"

1
FOR SATURATION PROPERTIES ENTER "0", FOR FLUID ENTER "1"

0
FOR A SINGLE POINT ENTER "0", FOR A TABLE ENTER "1"

0
FOR SATURATED LIQUID ENTER "0", FOR VAPOR ENTER "1"

0
TO ENTER WITH TEMPERATURE ENTER "0", FOR PRESSURE "1"

1
ENTER A PRESSURE(MPA)   0 RESTARTS THE PROGRAM

.1

  P      T      DEN      E      H      S     CV    CP   SOUND  VISC   COND   DIEL
  MPA    K      MOL/L   === J/MOL ==  ==== J/MOL-K === M/S    PA-S   MW/M-K  ==
                                                              E+6
   .100  20.23 35.144  -520.  -517.  16.1 11.4  19.4 1102.              1.22999

ENTER A PRESSURE(MPA)   0 RESTARTS THE PROGRAM
```

The source of the helium equation of state is McCarty [10].

Estimated Uncertainties (%)

Property	Liquid Below T_c	Gas Below T_c	Fluid Above T_c
Pressure	10.0	0.2	0.2
Density	0.5	0.2	0.2
Temperature	0.5	0.2	0.2
Enthapy & Internal Energy	2.0	1.0	1.0
Entropy	2.0	1.0	1.0
C_p and C_v	2.0	2.0	0.5
Speed of Sound	2.0	1.0	0.5
Thermal Conductivity	10.0	10.0	10.0
Viscosity	8.0	8.0	10.0

Fixed Points

	Pressure, MPa	Density, M/L	Temperature, K
Critical Point	0.2275	17.399	5.2014
Lambda Point Liquid	0.00496	36.534 3	2.172
Lambda Point Vapor	0.00496	0.2904	2.172

Temperature Range 2 - 1500 K

Pressure Range 0 - 100 MPa

Sample Calculations

```
1
FOR SATURATION PROPERTIES ENTER "0", FOR FLUID ENTER "1"

0
FOR A SINGLE POINT ENTER "0", FOR A TABLE ENTER "1"

0
FOR SATURATED LIQUID ENTER "0", FOR VAPOR ENTER "1"

0
TO ENTER WITH TEMPERATURE ENTER "0", FOR PRESSURE "1"

1
ENTER A PRESSURE( MPA)

.1

   P      T       DEN      E       H       S'    CV     CP    SOUND  VISC   COND  DIEL
   MPA    K       MOL/L   === J/MOL ==   ==== J/MOL-K ===    M/S   PA-S  MW/M-K  ==
                                                                     E+6
    .100    4.21 31.291    -24.    -20.   14.2   9.5   19.7   173.   31.8   19.6 1.04925
```

The source of the nitrogen equation of state is Jacobsen, et al. [6] and Ely and Straty [11].

Estimated Uncertainties (%)

Property	Liquid Below T_c	Gas Below T_c	Fluid Above T_c
Pressure	5.0	0.3	0.3
Density	0.5	0.3	0.2
Temperature	0.5	0.3	0.2
Enthapy & Internal Energy	3.0	1.0	1.0
Entropy	2.0	1.0	1.0
C_p and C_v	5.0	5.0	5.0
Speed of Sound	2.0	0.25	1.0
Thermal Conductivity	4.0	4.0	6.0
Viscosity	2.0	2.0	2.0

Fixed Points

	Pressure, MPa	Density, M/L	Temperature, K
Critical Point	3.4100	11.21	126.26
Triple Point Liquid	0.1246	30.977	63.15
Triple Point Vapor	0.1246	0.2396	63.15

Temperature Range 63.15 - 1900 K

Pressure Range 0 - 1000 MPa

Sample Calculations

```
THE RANGE OF TEMPERATURE FOR NITROGEN IS 63.15 TO 1900 K
WITH PRESSURES TO 1000 MPA
FOR ENGINEERING UNITS ENTER "0", FOR METRIC ENTER "1"

1
FOR SATURATION PROPERTIES ENTER "0", FOR FLUID ENTER "1"

0
FOR A SINGLE POINT ENTER "0", FOR A TABLE ENTER "1"

0
FOR SATURATED LIQUID ENTER "0", FOR VAPOR ENTER "1"

0
TO ENTER WITH TEMPERATURE ENTER "0", FOR PRESSURE "1"

1
ENTER A PRESSURE(MPA)

.1

  P      T       DEN      E       H       S     CV     CP    SOUND  VISC   COND   DIEL
  MPA    K       MOL/L   === J/MOL ==   ==== J/MOL-K ===    M/S    PA-S   MW/M-K  ==
                                                                    E+6
   .100  77.25  28.881  -3411.  -3407.   79.5  27.8   57.8   941.  152.2  133.8  1.43386
```

The source of the oxygen equation of state is Weber [10] and Younglove [12].

Estimated Uncertainties (%)

Property	Liquid Below T_c	Gas Below T_c	Fluid Above T_c
Pressure	5.0	0.25	0.15
Density	0.1	0.25	0.15
Temperature	0.1	0.20	0.10
Enthapy & Internal Energy	0.5	0.25	0.50
Entropy	0.5	0.25	0.50
C_p and C_v	3.0	5.0	3.0
Speed of Sound	2.0	0.50	0.50
Thermal Conductivity	4.0	4.0	6.0
Viscosity	2.0	2.0	2.0

Fixed Points

	Pressure, MPa	Density, M/L	Temperature, K
Critical Point	5.0422	13.63	154.481
Triple Point Liquid	0.1490×10^{-3}	40.820	54.359
Triple Point Vapor	0.1490×10^{-3}	0.3275×10^{-3}	54.359

Temperature Range 54.359 to 400 K

Pressure Range 0 - 120 MPa

Sample Calculations

```
THE RANGE OF TEMPERATURE FOR OXYGEN IS 54.359 TO 400 K
WITH PRESSURES TO 120 MPA
FOR ENGINEERING UNITS ENTER "0", FOR METRIC ENTER "1"

1
FOR SATURATION PROPERTIES ENTER "0", FOR FLUID ENTER "1"

0
FOR A SINGLE POINT ENTER "0", FOR A TABLE ENTER "1"

0
FOR SATURATED LIQUID ENTER "0", FOR VAPOR ENTER "1"

0
TO ENTER WITH TEMPERATURE ENTER "0", FOR PRESSURE "1"

1
ENTER A PRESSURE( MPA)

.1

   P      T       DEN      E       H       S     CV     CP    SOUND  VISC   COND  DIEL
   MPA    K       MOL/L   === J/MOL ==  ==== J/MOL-K ===    M/S    PA-S MW/M-K  ==
                                                                     E+6
    .100  90.07 35.677 -4272.  -4270.   94.1 29.6   54.2   906.  195.3 152.0 1.48734
```

The source of the argon equation of state is Stewart, et al. [13].

Estimated Uncertainties (%)

Property	Liquid Below T_c	Gas Below T_c	Fluid Above T_c
Pressure	10.0	0.3	0.3
Density	0.25	0.3	0.3
Temperature	0.25	0.3	0.3
Enthapy & Internal Energy	2.0	1.0	1.5
Entropy	1.0	1.0	1.0
C_p and C_v	5.0	5.0	5.0
Speed of Sound	5.0	5.0	5.0
Thermal Conductivity	4.0	4.0	6.0
Viscosity	2.0	2.0	2.0

Fixed Points

	Pressure, MPa	Density, M/L	Temperature, K
Critical Point	4.8980	13.41	150.86
Triple Point Liquid	0.0689	35.40	83.8
Triple Point Vapor	0.0689	0.1015×10^{-3}	83.8

Temperature Range 83.8 to 400 K

Pressure Range 0 - 100 MPa

Sample Calculations

```
THE TEMPERATURE RANGE FOR ARGON IS 83.8 TO 400 K
WITH PRESSURES TO 100 MPA
FOR ENGINEERING UNITS ENTER "0", FOR METRIC ENTER "1"

1
FOR SATURATION PROPERTIES ENTER "0", FOR FLUID ENTER "1"

0
FOR A SINGLE POINT ENTER "0", FOR A TABLE ENTER "1"

0
FOR SATURATED LIQUID ENTER "0", FOR VAPOR ENTER "1"

0
TO ENTER WITH TEMPERATURE ENTER "0", FOR PRESSURE "1"

1
ENTER A PRESSURE( MPA)

.1

   P      T       DEN      E       H       S     CV     CP    SOUND  VISC   COND   DIEL
   MPA    K       MOL/L   === J/MOL ==   ====  J/MOL-K ===   M/S    PA-S   MW/M-K  ==
                                                                      E+6
    .100  87.16  34.914  -4714.  -4711.   54.8  22.3   44.7   815.  261.2  128.5
```

The source of the nitrogen trifluoride equation of state is Goodwin and Weber [14].

Estimated Uncertainties (%)*

Property	Liquid Below T_c	Gas Below T_c	Fluid Above T_c
Pressure	5.0	0.2	0.1
Density	0.1	0.2	0.1
Temperature	0.1	0.1	0.1
Enthapy & Internal Energy	2.0	2.0	2.0
Entropy	2.0	2.0	2.0
C_p and C_v	5.0	5.0	5.0
Speed of Sound	5.0	5.0	5.0

Fixed Points

	Pressure, MPa	Density, M/L	Temperature, K
Critical Point	4.4607	7.92	234.0
Triple Point Liquid	0.1854×10^{-6}	26.32	66.35
Triple Point Vapor	0.1854×10^{-6}	0.33612×10^{-6}	66.35

Temperature Range 66.36 to 500 K

Pressure Range 0 - 50 MPa

Sample Calculations

```
THE RANGE OF TEMPERATURE OFR NITROGEN TRIFLUORIDE IS
66.36 TO 500 K, WITH PRESSURES TO 50 MPA
FOR ENGINEERING UNITS ENTER "0", FOR METRIC ENTER "1"

1
FOR SATURATION PROPERTIES ENTER "0", FOR FLUID ENTER "1"

0
FOR A SINGLE POINT ENTER "0", FOR A TABLE ENTER "1"

0
FOR SATURATED LIQUID ENTER "0", FOR VAPOR ENTER "1"

0
TO ENTER WITH TEMPERATURE ENTER "0", FOR PRESSURE "1"

1
ENTER A PRESSURE( MPA)

.1

  P      T       DEN      E       H       S     CV     CP    SOUND  VISC  COND  DIEL
  MPA    K       MOL/L   === J/MOL ==   ==== J/MOL-K ===    M/S    PA-S MW/M-K  ==
                                                                    E+6
   .100 143.92 21.669 -6846. -6841. 147.6 40.3  72.2  759.
```

*Estimates not from original source.

The source of the methane equation of state is Ely, et al. [3].

Estimated Uncertainties (%)*

Property	Liquid Below T_c	Gas Below T_c	Fluid Above T_c
Pressure	5.0	0.25	0.25
Density	0.1	0.25	0.25
Temperature	0.1	0.25	0.25
Enthapy & Internal Energy	1.0	0.5	0.50
Entropy	0.5	0.5	0.50
C_p and C_v	2.0	5.0	2.00
Speed of Sound	1.0	0.3	0.3
Thermal Conductivity	5.0	5.0	4.0
Viscosity	3.0	3.0	2.0

Fixed Points

	Pressure, MPa	Density, M/L	Temperature, K
Critical Point	4.599	10.23	190.55
Triple Point Liquid	0.01174	28.1511	90.68
Triple Point Vapor	0.01174	0.01569×10^{-6}	90.68

Temperature Range 90.68 to 600 K

Pressure Range 0 - 200 MPa

Sample Calculations

```
THE RANGE OF TEMPERATURE FOR METHANE IS 90.68 TO 600 K
WITH PRESSURES TO 200 MPA
FOR ENGINEERING UNITS ENTER "0", FOR METRIC ENTER "1"

1
FOR SATURATION PROPERTIES ENTER "0", FOR FLUID ENTER "1"

0
FOR A SINGLE POINT ENTER "0", FOR A TABLE ENTER "1"

0
FOR SATURATED LIQUID ENTER "0", FOR VAPOR ENTER "1"

0
TO ENTER WITH TEMPERATURE ENTER "0", FOR PRESSURE "1"

1
ENTER A PRESSURE( MPA)

.1

  P      T       DEN      E       H       S     CV     CP    SOUND  VISC   COND   DIEL
  MPA    K       MOL/L   === J/MOL ==   ====  J/MOL-K ===   M/S   PA-S   MW/M-K  ==
                                                                    E+6
   .100 111.47 26.355 -4629.  -4625.   79.0  32.9   55.5 1336.  117.6  188.8 1.62653
```

*Estimates not from original source.

The source of the ethylene equation of state is McCarty and Jacobsen [15].

Estimated Uncertainties (%)*

Property	Liquid Below T_c	Gas Below T_c	Fluid Above T_c
Pressure	5.0	0.15	0.15
Density	0.15	0.15	0.15
Temperature	0.15	0.15	0.15
Enthapy & Internal Energy	2.0	1.0	1.0
Entropy	2.0	1.0	1.0
C_p and C_v	5.0	2.0	2.0
Speed of Sound	3.0	1.0	1.0

Fixed Points

	Pressure, MPa	Density, M/L	Temperature, K
Critical Point	5.0403	7.634	282.343
Triple Point Liquid	0.12×10^{-3}	23.389	103.986
Triple Point Vapor	0.12×10^{-3}	0.14×10^{-3}	103.986

Temperature Range 104 to 400 K

Pressure Range 0 - 40 MPa

Sample Calculations

```
 THE TEMPERATURE RANGE FOR ETHYLENE IS 104 TO 400 K
 WITH PRESSURES TO 40 MPA
 FOR ENGINEERING UNITS ENTER "0", FOR METRIC ENTER "1"

 1
 FOR SATURATION PROPERTIES ENTER "0", FOR FLUID ENTER "1"

 0
 FOR A SINGLE POINT ENTER "0", FOR A TABLE ENTER "1"

 0
 FOR SATURATED LIQUID ENTER "0", FOR VAPOR ENTER "1"

 0
 TO ENTER WITH TEMPERATURE ENTER "0", FOR PRESSURE "1"

 1
 ENTER A PRESSURE( MPA)

 .1

   P      T       DEN      E       H       S     CV     CP    SOUND  VISC  COND  DIEL
   MPA    K       MOL/L   === J/MOL ==   ==== J/MOL-K ===    M/S    PA-S MW/M-K  ==
                                                                      E+6
    .100 169.19 20.256 -8017. -8012. 117.6 38.2  67.9 1312.
```

*Estimates not from original source.

The source of the ethane equation of state is Ely, et al. [3].

Estimated Uncertainties (%)*

Property	Liquid Below T_c	Gas Below T_c	Fluid Above T_c
Pressure	5.0	0.25	0.15
Density	0.1	0.25	0.15
Temperature	0.1	0.25	0.15
Enthapy & Internal Energy	1.0	1.0	1.0
Entropy	1.0	1.0	1.0
C_p and C_v	5.0	5.0	5.0
Speed of Sound	5.0	5.0	5.0

Fixed Points

	Pressure, MPa	Density, M/L	Temperature, K
Critical Point	4.8714	6.8	305.33
Triple Point Liquid	0.11308×10^{-5}	21.68	90.348
Triple Point Vapor	0.11308×10^{-5}	0.1515×10^{-5}	90.348

Temperature Range 90.33 to 600 K

Pressure Range 0 - 70 MPa

Sample Calculations

```
THE RANGE OF TEMPERATURE FOR ETHANE IS 90.35 TO 600 K
WITH PRESSURES TO 70 MPA
FOR ENGINEERING UNITS ENTER "0", FOR METRIC ENTER "1"

1
FOR SATURATION PROPERTIES ENTER "0", FOR FLUID ENTER "1"

0
FOR A SINGLE POINT ENTER "0", FOR A TABLE ENTER "1"

0
FOR SATURATED LIQUID ENTER "0", FOR VAPOR ENTER "1"

0
TO ENTER WITH TEMPERATURE ENTER "0", FOR PRESSURE "1"

1
ENTER A PRESSURE( MPA)

.1

   P      T       DEN      E       H       S     CV     CP    SOUND  VISC   COND   DIEL
   MPA    K       MOL/L   === J/MOL ==   ==== J/MOL-K ===    M/S    PA-S MW/M-K   ==
                                                                      E+6
    .100 184.31 18.105 -8263.  -8258.  126.8 42.6   73.1 1324.                  1.75728
```

*Estimates not from original source.

The source of the propane equation of state is Ely, et al. [3].

Estimated Uncertainties (%)*

Property	Liquid Below T_c	Gas Below T_c	Fluid Above T_c
Pressure	5.0	0.25	0.15
Density	0.1	0.25	0.15
Temperature	0.1	0.25	0.15
Enthapy & Internal Energy	1.0	1.0	1.5
Entropy	1.0	1.0	1.5
C_p and C_v	5.0	5.0	5.0
Speed of Sound	5.0	5.0	5.0
Thermal Conductivity	5.0	5.0	5.0
Viscosity	3.0	3.0	3.0

Fixed Points

	Pressure, MPa	Density, M/L	Temperature, K
Critical Point	4.247	5.00	369.85
Triple Point Liquid	0.1690×10^{-9}	16.630	85.47
Triple Point Vapor	0.1690×10^{-9}	0.2238×10^{-9}	85.47

Temperature Range 85.47 to 600 K

Pressure Range 0 - 100 MPa

Sample Calculations

```
 THE RANGE OF TEMPERATURE FOR PROPANE IS 85.47 TO 600 K
 WITH PRESSURES TO 100 MPA
 FOR ENGINEERING UNITS ENTER "0", FOR METRIC ENTER "1"

 1
 FOR SATURATION PROPERTIES ENTER "0", FOR FLUID ENTER "1"

 0
 FOR A SINGLE POINT ENTER "0", FOR A TABLE ENTER "1"

 0
 FOR SATURATED LIQUID ENTER "0", FOR VAPOR ENTER "1"

 0
 TO ENTER WITH TEMPERATURE ENTER "0", FOR PRESSURE "1"

 1
 ENTER A PRESSURE( MPA)

 .1

   P      T       DEN      E       H       S     CV     CP    SOUND  VISC   COND   DIEL
   MPA    K       MOL/L   === J/MOL ==   ==== J/MOL-K ===    M/S    PA-S MW/M-K   ==
                                                                      E+6
    .100 230.78 13.188 -8826. -8818. 171.0 64.0  99.0 1160.              1.80350
```

*Estimates not from original source.

The source of the isobutane equation of state is Ely, et al. [3].

Estimated Uncertainties (%)*

Property	Liquid Below T_c	Gas Below T_c	Fluid Above T_c
Pressure	5.0	0.20	0.15
Density	0.1	0.20	0.15
Temperature	0.1	0.20	0.15
Enthapy & Internal Energy	1.0	1.0	1.0
Entropy	1.0	1.0	1.0
C_p and C_v	3.0	3.0	3.0
Speed of Sound	3.0	3.0	3.0
Thermal Conductivity	5.0	5.0	5.0
Viscosity	3.0	3.0	3.0

Fixed Points

	Pressure, MPa	Density, M/L	Temperature, K
Critical Point	3.690	3.86	407.85
Triple Point Liquid	0.19481×10^{-7}	12.755	113.55
Triple Point Vapor	0.19481×10^{-7}	0.20633×10^{-7}	113.55

Temperature Range 113.55 to 600 K

Pressure Range 0 - 35 MPa

Sample Calculations

```
 THE RANGE OF TEMPERATURE FOR ISO BUTANE IS
 113.55 TO 600 K
 WITH PRESSURES TO 35 MPA
 FOR ENGINEERING UNITS ENTER "0", FOR METRIC ENTER "1"

 1
 FOR SATURATION PROPERTIES ENTER "0", FOR FLUID ENTER "1"

 0
 FOR A SINGLE POINT ENTER "0", FOR A TABLE ENTER "1"

 0
 FOR SATURATED LIQUID ENTER "0", FOR VAPOR ENTER "1"

 0
 TO ENTER WITH TEMPERATURE ENTER "0", FOR PRESSURE "1"

 1
 ENTER A PRESSURE(MPA)

 .1

   P      T       DEN      E       H       S     CV     CP    SOUND  VISC   COND   DIEL
   MPA    K       MOL/L   ===  J/MOL  ==   ====  J/MOL-K  ===   M/S   PA-S   MW/M-K  ==
                                                                      E+6
    .100 261.20 10.220 -7116. -7106. 200.8 92.1 130.4 1010. 229.2 112.2 1.82016
```

*Estimates not from original source.

The source of the normal butane equation of state is Ely, et al. [3].

Estimated Uncertainties (%)*

Property	Liquid Below T_c	Gas Below T_c	Fluid Above T_c
Pressure	5.0	0.20	0.15
Density	0.1	0.20	0.15
Temperature	0.1	0.20	0.15
Enthapy & Internal Energy	1.0	1.0	1.0
Entropy	1.0	1.0	1.0
C_p and C_v	3.0	3.0	3.0
Speed of Sound	3.0	3.0	3.0
Thermal Conductivity	5.0	5.0	5.0
Viscosity	3.0	3.0	3.0

Fixed Points

	Pressure, MPa	Density, M/L	Temperature, K
Critical Point	3.796	3.92	425.16
Triple Point Liquid	0.6736×10^{-6}	12.65	134.86
Triple Point Vapor	0.6736×10^{-6}	0.60071×10^{-6}	134.86

Temperature Range 134.65 to 500 K

Pressure Range 0 - 70 MPa

Sample Calculations

```
 THE RANGE OF TEMPERATURE FOR NORMAL BUTANE IS
 134.68 TO 500 K
 WITH PRESSURES TO 70 MPA
 FOR ENGINEERING UNITS ENTER "0", FOR METRIC ENTER "1"

 1
 FOR SATURATION PROPERTIES ENTER "0", FOR FLUID ENTER "1"

 0
 FOR A SINGLE POINT ENTER "0", FOR A TABLE ENTER "1"

 0
 FOR SATURATED LIQUID ENTER "0", FOR VAPOR ENTER "1"

 0
 TO ENTER WITH TEMPERATURE ENTER "0", FOR PRESSURE "1"

 1
 ENTER A PRESSURE(MPA)

 .1

   P      T       DEN      E       H       S     CV     CP    SOUND  VISC   COND   DIEL
   MPA    K       MOL/L    ===  J/MOL  ==   ====  J/MOL-K  ===   M/S   PA-S   MW/M-K  ==
                                                                      E+6
    .100 272.29 10.348 -5959. -5949. 218.1 95.6 134.4 1036. 204.2 117.2 1.81181
```

*Estimates not from original source.

Appendix B

Sample Computer Sessions

```
helium


THIS PROGRAM PROVIDES THE THERMODYNAMIC PROPERTIES OF HELIUM FROM 2 TO 1500 K
WITH PRESSURES TO 100 MPA



WHEN THE PROGRAM ASKS FOR A PRESSURE, DENSITY AND TEMPERATURE,
ENTER ANY TWO AND A ZERO FOR THE THIRD.
TO TERMINATE THE PROGRAM ENTER ZERO FOR ALL THREE.


FOR ENGINEERING UNITS ENTER "0", FOR METRIC ENTER "1"

1
FOR SATURATION PROPERTIES ENTER "0", FOR FLUID ENTER "1"

1
FOR A SINGLE POINT ENTER "0", FOR A TABLE ENTER "1"

1
ENTER A PRESSURE(MPA), A STARTING TEMPERATURE(K), A FINAL TEMPERATURE AND A
TEMPERATURE INCREMENT AND IN THAT ORDER, TO RESTART PROGRAM ENTER "0,0,0,0"

.1,3,10,1

  P      T       DEN      E       H       S     CV     CP    SOUND  VISC   COND  DIEL
  MPA    K       MOL/L   === J/MOL ==  ==== J/MOL-K === M/S    PA-S MW/M-K  ==
                                                                  E+6
   .100    3.00 35.794   -39.    -36.    9.8   7.6    9.4   222.   38.5   18.1 1.05646
   .100    4.00 32.477   -27.    -24.   13.3   9.1   16.3   185.   33.3   19.6 1.05114
   .100    5.00  2.935    52.     86.   39.1  12.7   27.1   120.   13.9   11.1 1.00456
   .100    6.00  2.252    67.    111.   43.7  12.5   24.0   137.   15.8   12.4 1.00350
   .100    7.00  1.855    81.    135.   47.3  12.5   22.8   151.   17.6   13.8 1.00288
   .100    8.00  1.586    94.    157.   50.3  12.5   22.2   163.   19.3   15.1 1.00246
   .100    9.00  1.389   107.    179.   52.9  12.5   21.9   174.   21.0   16.3 1.00216
   .100   10.00  1.238   120.    201.   55.2  12.5   21.7   185.   22.6   17.5 1.00192

ENTER A PRESSURE(MPA), A STARTING TEMPERATURE(K), A FINAL TEMPERATURE AND A
TEMPERATURE INCREMENT AND IN THAT ORDER, TO RESTART PROGRAM ENTER "0,0,0,0"

0,0,0,0


FOR MORE PROPERTIES ENTER 0, TO TERMINATE ENTER 1
1
Stop - Program terminated.
```

```
MIPROPS


FOR INFORMATION ON HOW TO USE THIS PROGRAM, ENTER "0"  OTHERWISE, ENTER "1"


0

ENTER A NUMBER TO SELECT A FLUID.
ANY ENTRY OTHER THAN A NUMBER WILL TERMINATE THE PROGRAM.
WHEN THE PROGRAM ASKS FOR A PRESSURE, DENSITY AND TEMPERATURE,
ENTER ANY TWO AND A ZERO FOR THE THIRD.  TO SELECT ANOTHER
FLUID ENTER ZERO FOR ALL THREE.
 SELECT A FLUID BY ENTERING THE CORRESPONDING NUMBER

1=ARGON,       2=ETHYLENE,                3=PARA HYDROGEN,      4=METHANE
5=NITROGEN,    6=NITROGEN TRIFLUORIDE,    7=OXYGEN,             8=ETHANE
9=PROPANE,    10=ISO BUTANE,             11=NORMAL BUTANE,     12=STOP

1
THE TEMPERATURE RANGE FOR ARGON IS 83.8 TO 400 K
WITH PRESSURES TO 100 MPA
FOR ENGINEERING UNITS ENTER "0", FOR METRIC ENTER "1"

1
FOR SATURATION PROPERTIES ENTER "0", FOR FLUID ENTER "1"

1
FOR A SINGLE POINT ENTER "0", FOR A TABLE ENTER "1"

1
ENTER A PRESSURE(MPA), A STARTING TEMPERATURE(K), A FINAL TEMPERATURE AND A
TEMPERATURE INCREMENT AND IN THAT ORDER, TO RESTART PROGRAM ENTER "0,0,0,0"

1,200,300,20

  P      T       DEN      E       H       S     CV     CP    SOUND  VISC  COND  DIEL
  MPA    K       MOL/L  === J/MOL ==  ==== J/MOL-K ===   M/S    PA-S MW/M-K  ==
                                                                    E+6
  1.000 200.00    .619   2384.   3999.  126.9 12.7   22.2   262.   16.3  13.2
  1.000 220.00    .559   2648.   4438.  128.9 12.6   21.8   275.   17.7  14.2
  1.000 240.00    .509   2908.   4873.  130.8 12.6   21.6   288.   19.1  15.3
  1.000 260.00    .468   3167.   5304.  132.6 12.6   21.5   301.   20.4  16.3
  1.000 280.00    .433   3423.   5732.  134.2 12.6   21.4   312.   21.8  17.3
  1.000 300.00    .403   3679.   6159.  135.6 12.5   21.3   324.   23.1  18.3

ENTER A PRESSURE(MPA), A STARTING TEMPERATURE(K), A FINAL TEMPERATURE AND A
TEMPERATURE INCREMENT AND IN THAT ORDER, TO RESTART PROGRAM ENTER "0,0,0,0"
```

Appendix C

Program Listings

```
      IMPLICIT REAL*8(A-H)
      IMPLICIT REAL*8(O-Z)
      IMPLICIT INTEGER*4(I-N)
      DIMENSION G(32),VP(9)
      COMMON/DATA/G,R,GAMMA,VP,DTP,PCC,PTP,TCC,TTP,TUL,TLL,PUL,DCC
      COMMON/CONT/IF
      COMMON/CRIT/EM,EOK,RM,TC,DC,X,PC,SIG
      COMMON/DIEL/BX(6),PX(6)
 1201 FORMAT(//'  THIS PROGRAM PROVIDES THE THERMODYNAMIC PROPERTIES OF
     111 FLUIDS',/,'              PARA HYDROGEN, NITROGEN, OXYGEN, ARGON
     2'/'          NITROGEN TRIFLOURIDE, METHANE, ETHANE, ETHYLENE'/
     3'               PROPANE, ISO BUTANE AND NORMAL BUTANE'//)
      WRITE(*,1201)
      WRITE(*,1202)
 1202 FORMAT('                              WRITTEN BY'//
     A'                        ROBERT D. MCCARTY'/
     1'                     THERMOPHYSICS DIVISION'/
     2'                  CENTER FOR CHEMICAL ENGINEERING'/
     3'                    NATIONAL BUREAU OF STANDARDS'/
     4'                         BOULDER, COLORADO'//
     5'                           DISTRIBUTED BY'//
     A'                 THE OFFICE OF STANDARD REFERENCE DATA'/
     6'              NATIONAL BUREAU OF STANDARDS, WASHINGTON, DC'/)

 1000 FORMAT(//' FOR INFORMATION ON HOW TO USE THIS PROGRAM, ENTER "0" '
     A ' OTHERWISE, ENTER "1"'//)
      WRITE(*,1000)
      IP=3
      READ(*,1010)I
      IF(I.EQ.0)CALL INFO
 1010 FORMAT(I1)
  110 WRITE(*,1020)
      WRITE(*,1030)
 1020 FORMAT('  SELECT A FLUID BY ENTERING THE CORRESPONDING NUMBER',/)
 1030 FORMAT('  1=PARA HYDROGEN,    2=NITROGEN,                  3=OXYGEN,'
     A,/,     '  4=ARGON,            5=NITROGEN TRIFLUORIDE,     6=METHANE,
     B',/,    '  7=ETHANE,           8=ETHYLENE,                  9=PROPANE,
     C',/,    ' 10=ISO BUTANE,      11=NORMAL BUTANE,           12=STOP',/)
      READ(*,*)IF
      CALL FDATA(IF)
  120 WRITE(*,1040)
 1040 FORMAT(' FOR ENGINEERING UNITS ENTER "0", FOR METRIC ENTER "1"',/)
      READ(*,1010)IU
      WRITE(*,1050)
 1050 FORMAT(' FOR SATURATION PROPERTIES ENTER "0", FOR FLUID ENTER '
     A '"1"',/)
      READ(*,1010)IC
      WRITE(*,1060)
 1060 FORMAT(' FOR A SINGLE POINT ENTER "0", FOR A TABLE ENTER "1"',/)
      READ(*,1010)IV
  160 IF(IC.EQ.0)GO TO 240
      IF(IV.EQ.1)GO TO 330
  170 IF(IU.EQ.0)GO TO 180
      WRITE(*,1080)
      READ(*,*)P,D,T
      GO TO 190
  180 WRITE(*,1070)
 1070 FORMAT(' ENTER PRESSURE(PSIA), DENSITY(LB/CU FT), AND TEMPERATURE'
```

```
    A '(F)',/)
     READ(*,*)P,D,T
     P=(P/14.695949D0)*.101325D0
     D=D*16.01846371D0/EM
     T=(T-32.D0)/1.8D0+273.15D0
 190 IF(P.LE.0.0D0.AND.D.LE.0.0D0)GO TO 110
     IF(P.GT.0.0D0.AND.D.GT.0.0D0)GO TO 200
     IF(P.LE.0.0D0.AND.T.NE.0.0D0)GO TO 220
1080 FORMAT(' ENTER PRESSURE(MPA), DENSITY(MOL/L), AND TEMPERATURE(K)'
    A /)
     IF(P.NE.0.0D0.AND.T.NE.0.0D0)GO TO 210
     GO TO 110
 200 T=FIND T(P,D)
     CALL LIMITS(P,T,IL)
     IF(IL.LE.0)GO TO 170
     GO TO 230
 210 CALL LIMITS(P,T,IL)
     IF(IL.LE.0)GO TO 170
     D=FIND D(P,T)
     GO TO 230
 220 P=FIND P(D,T)
     CALL LIMITS(P,T,IL)
     IF(IL.LE.0)GO TO 170
 230 CALL REPRO(P,D,T,IU,IV,IC,IP,TF,DELT)
     GO TO 170
 240 WRITE(*,1090)
1090 FORMAT(' FOR SATURATED LIQUID ENTER "0", FOR VAPOR ENTER "1"',/)
     READ(*,1010)IP
     IF(IV.EQ.1)GO TO 330
     WRITE(*,1095)
1095 FORMAT(' TO ENTER WITH TEMPERATURE ENTER "0", FOR PRESSURE "1"',/)
     READ(*,1010)II
     IF(II.EQ.1)GO TO 290
 250 IF(IU.EQ.1)GO TO 260
1100 FORMAT(' ENTER A TEMPERATURE IN DEGREES F',/)
     WRITE(*,1100)
     READ(*,*)TI
     T=(TI-32.D0)/1.8D0+273.15D0
     GO TO 270
 260 WRITE(*,1110)
1110 FORMAT(' ENTER A TEMPERATURE(K)   0 RESTARTS THE PROGRAM'/)
     READ(*,*)T
 270 IF(T.LT..000001D0)GO TO 110
     IF(T.GT.TCC.OR.T.LT.TTP)GO TO 280
     P=VPN(T)
     IF(IP.EQ.0)P=P+.00001D0
     D=FIND D(P,T)
     CALL RE PRO(P,D,T,IU,IV,IC,IP,TF,DELT)
     WRITE(*,1111)
1111 FORMAT(' ENTER 1 FOR MORE OR 0 TO RESTART PROGRAM'/)
     READ(*,*)ISAT
     IF(ISAT.EQ.1)GO TO 250
     GO TO 110
 280 X1=(TTP-273.15D0)*1.8D0+32.D0
     X2=(TCC-273.15D0)*1.8D0+32.D0
     WRITE(*,1120)TTP,TCC,X1,X2
1120 FORMAT(' FOR SATURATION ',F6.2,' < TEMP < ',F6.2,' K',/,
    A ' OR ',F7.2,' < TEMP < ',F7.2,' F',/)
     GO TO 250
```

```
 290 IF(IU.EQ.1)GO TO 300
     WRITE(*,1130)
1130 FORMAT(' ENTER A PRESSURE IN LB/SQ IN   0 RESTARTS THE PROGRAM'/)
     READ(*,*)PI
     IF(PI.LE.0.0D0)GO TO 110
     P=(PI/14.695949D0)*.101325D0
     GO TO 310
 300 WRITE(*,1140)
1140 FORMAT(' ENTER A PRESSURE(MPA)   0 RESTARTS THE PROGRAM'/)
     READ(*,*)PI
     IF(PI.LE.0.0D0)GO TO 110
     P=PI
 310 IF(P.GT.PCC.OR.P.LT.PTP)GO TO 320
4000 FORMAT(D20.5)
     T=FIND TV(P)
     P=VPN(T)
     IF(IP.EQ.0)P=P+.00001D0
     D=FIND D(P,T)
     CALL RE PRO(P,D,T,IU,IV,IC,IP,TF,DELT)
     GO TO 290
 320 PTPF=PTP*14.695949D0/.101325D0
     PCCF=PCC*14.695949D0/.101325D0
     WRITE(*,1150) PTP,PCC,PTPF,PCCF
1150 FORMAT(' YOUR INPUT PRESSURE IS OUTSIDE THE RANGE OF SATURATION'
    A ' PRESSURES'/' FOR THIS FLUID THE RANGE IS ',F6.5,' TO ',F6.3,
    B ' MPA'/' OR ',F6.2,' TO ',F6.1,' PSIA'/'  TRY AGAIN',/)
     GO TO 290
 330 IF(IC.EQ.1)GO TO 370
     IF(IU.EQ.1)GO TO 340
     WRITE(*,1160)
1160 FORMAT('  ENTER A STARTING TEMPERATURE, A FINAL TEMPERATURE'
    A /' AND A TEMPERATURE INCREMENT, IN DEGREES F AND IN THAT ORDER'/)
     READ(*,*)TS,TF,DELT
     IF(DELT.LE.0.0D0)GO TO 110
     TS=(TS-32.D0)/1.8D0+273.15D0
     TF=(TF-32.D0)/1.8D0+273.15D0
     DELT=DELT/1.8D0
     IF(TS.LT.TTP.OR.TS.GT.TCC)GO TO 360
     IF(TF.LT.TTP.OR.TF.GT.TCC)GO TO 360
     GO TO 350
 340 WRITE(*,1170)
1170 FORMAT(' ENTER A STARTING TEMPERATURE, A FINAL TEMPERATURE'
    1/' AND A TEMPERATURE INCREMENT IN KELVINS AND IN THAT ORDER',/)
     READ(*,*)TS,TF,DELT
     IF(DELT.LE.0.0D0)GO TO 110
     IF(TS.LT.TTP.OR.TS.GT.TCC)GO TO 360
     IF(TF.LT.TTP.OR.TF.GT.TCC)GO TO 360
 350 T=TS
     P=VPN(T)
     IF(IP.EQ.0.0D0)P=P+.00001D0
     D=FIND D(P,T)
     CALL RE PRO(P,D,T,IU,IV,IC,IP,TF,DELT)
     GO TO 330
 360 X1=(TTP-273.15D0)*1.8D0+32.D0
     X2=(TCC-273.15D0)*1.8D0+32.D0
     WRITE(*,1180)TTP,TCC,X1,X2
1180 FORMAT(' FOR SATURATION,  ',F6.2,' < TEMP < ',F6.2,' K',/,
    A ,13X,'OR, ',F7.1,' < TEMP < ',F7.1,' F.  TRY AGAIN.',/)
     GO TO 330
```

```
 370 IF(IU.EQ.1)GO TO 380
     WRITE(*,1190)
1190 FORMAT(' ENTER PRESSURE(PSIA), STARTING TEMPERATURE(F), FINAL '
    A 'TEMPERATURE AND A'/' TEMPERATURE INCREMENT'
    2' AND IN THAT ORDER, TO RESTART PROGRAM ENTER "0,0,0,0"',/)
     READ(*,*)PI,TS,TF,DELT
     IF(DELT.LE.0.0D0)GO TO 110
     P=(PI/14.695949D0)*.101325D0
     T=(TS-32.D0)/1.8D0+273.15D0
     TF=(TF-32.D0)/1.8D0+273.15D0
     DELT=DELT/1.8D0
     CALL LIMITS(P,T,IL)
     IF(IL.LE.0)GO TO 370
     CALL LIMITS(P,TF,IL)
     IF(IL.LE.0)GO TO 370
     GO TO 390
 380 WRITE(*,1200)
1200 FORMAT(' ENTER A PRESSURE(MPA), A STARTING TEMPERATURE(K), A '
    1'FINAL TEMPERATURE AND A'/' TEMPERATURE INCREMENT'
    2' AND IN THAT ORDER, TO RESTART PROGRAM ENTER "0,0,0,0"',/)
     READ(*,*)PI,TS,TF,DELT
     IF(DELT.LE.0.0D0)GO TO 110
     T=TS
     P=PI
     CALL LIMITS(P,T,IL)
     IF(IL.LE.O)GO TO 370
     CALL LIMITS(P,TF,IL)
     IF(IL.LE.0)GO TO 370
 390 D=FIND D(P,T)
     CALL RE PRO(P,D,T,IU,IV,IC,IP,TF,DELT)
     GO TO 370
 999 CONTINUE
     END
     SUBROUTINE REPRO(P,D,T,IU,IV,IC,IP,TF,DELT)
     IMPLICIT REAL*8(A-H)
     IMPLICIT REAL*8(O-Z)
     IMPLICIT INTEGER*4(I-N)
     DIMENSION G(32),VP(9)
     COMMON/DATA/G,R,GAMMA,VP,DTP,PCC,PTP,TCC,TTP,TUL,TLL,PUL,DCC
     COMMON/CONT/IF
     COMMON/CRIT/EM,EOK,RM,TC,DC,X,PC,SIG
     COMMON/CPID/GI(11),GH(11),GL(11)
     COMMON/HAN/CR,TCI
     N=500
     IF(IV.EQ.0)TF=T-1.D0
     IF(IU.EQ.0)GO TO 100
     WRITE(*,1000)
     WRITE(*,1010)
     WRITE(*,1020)
     GO TO 110
 100 WRITE(*,1000)
     WRITE(*,1030)
     WRITE(*,1040)
 110 CONTINUE
     DO 210 I=1,N
     IF(I.EQ.1)GO TO 120
     IF(D.LT.DCC.OR.T.GT.TCC)GO TO 111
     D=FIND D(P,T)
     GO TO 120
 111 DIN=D
     D=FINDM(P,T,DIN)
```

```
 120 H=ENTHAL(P,D,T)
     E=H-1000.D0*P/D
     S=ENTROP(D,T)
     W=SOUND(D,T)
     CPP=CP(D,T)
     CVV=CV(D,T)
     IF(IU.EQ.0)GO TO 160
     IF(IF.EQ.6.OR.IF.EQ.2.OR.IF.EQ.3) GO TO 150
     IF(IF.GT.9)GO TO 150
     IF(IF.EQ.4) GO TO 140
     IF(IF.EQ.1.OR.IF.EQ.7.OR.IF.EQ.9) GO TO 130
     WRITE(*,2000) P,T,D,E,H,S,CVV,CPP,W
     GO TO 200
 130 EPS=FDIEL(P,D,T)
     WRITE(*,2010) P,T,D,E,H,S,CVV,CPP,W,EPS
     GO TO 200
 140 TH=THERM(D,T)*1000.D0
     V=VISC(D,T)
     WRITE(*,2020) P,T,D,E,H,S,CVV,CPP,W,V,TH
     GO TO 200
 150 V=VISC(D,T)
     TH=THERM(D,T)*1000.D0
     EPS=FDIEL(P,D,T)
     WRITE(*,2030) P,T,D,E,H,S,CVV,CPP,W,V,TH,EPS
     GO TO 200
 160 H=H/(2.324445D0*EM)
     E=E/(2.324445D0*EM)
     S=S/(4.184001D0*EM)
     CPP=CPP/(4.184001D0*EM)
     CVV=CVV/(4.184001D0*EM)
     W=W*3.280840D0
     PO=(P/.101325D0)*14.695949D0
     DO=D*EM/16.01846371D0
     TO=T*1.8D0-459.67D0
     IF(IF.EQ.6.OR.IF.EQ.2.OR.IF.EQ.3) GO TO 190
     IF(IF.EQ.4) GO TO 180
     IF(IF.EQ.1) GO TO 170
     WRITE(*,3000) PO,TO,DO,E,H,S,CVV,CPP,W
     GO TO 200
 170 EPS=FDIEL(P,D,T)
     WRITE(*,3010) PO,TO,DO,E,H,S,CVV,CPP,W,EPS
     GO TO 200
 180 V=VISC(D,T)*.067196897D0
     TH=THERM(D,T)*.578176D0
     WRITE(*,3020) PO,TO,DO,E,H,S,CVV,CPP,W,V,TH
     GO TO 200
 190 V=VISC(D,T)*.067196897D0
     TH=THERM(D,T)*.578176D0
     EPS=FDIEL(P,D,T)
     WRITE(*,3030) PO,TO,DO,E,H,S,CVV,CPP,W,V,TH,EPS
 200 T=T+DELT
     IF(T.GT.TF+.01D0)GO TO 220
     IF(IC.EQ.0)P=VPN(T)
     IF(IP.EQ.0)P=P+.00001D0
 210 CONTINUE
 220 CONTINUE
     WRITE(*,1000)
1000 FORMAT(' ')
     RETURN
```

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1010 FORMAT(3X,'P',5X,'T',6X,'DEN',5X,'E',6X,'H',6X,'S',4X,'CV',4X,
    A 'CP',3X,'SOUND',2X,'VISC',2X,'COND',2X,'DIEL')
1020 FORMAT(3X,'MPA',3X,'K',6X,'MOL/L',2X,'=== J/MOL ==',2X,'==== ',
    A 'J/MOL-K ===',2X,'M/S',3X,'PA-S',1X,'MW/M-K',2X,'==',/,61X,'E+6')
1030 FORMAT(3X,'P',5X,'T',7X,'DENS',3X,'E',8X,'H',5X,'S',5X,'CV',
    A 4X,'CP',2X,'SOUND',1X,'VISC',2X,'COND',2X,'DIEL')
1040 FORMAT(3X,'PSIA',2X,'F',7X,'LB/',3X,'==== BTU/ ===',1X,'======',
    A ' BTU/ =====',2X,'F/S',3X,'LB/',2X,'BTU/',2X,'==',/,17X,'CU FT',
    B 6X,'LB',14X,'LB-F',13X,'FT-S',1X,'FT-HR-F',/,62X,'E+5')
2000 FORMAT(F8.3,F7.2,F7.3,2F7.0,F6.1,F5.1,F6.1,F6.0)
2010 FORMAT(F8.3,F7.2,F7.3,2F7.0,F6.1,F5.1,F6.1,F6.0,13X,F8.5)
2020 FORMAT(F8.3,F7.2,F7.3,2F7.0,F6.1,F5.1,F6.1,F6.0,F6.1,F6.1)
2030 FORMAT(F8.3,F7.2,F7.3,2F7.0,F6.1,F5.1,F6.1,F6.0,F6.1,F6.1,F8.5)
3000 FORMAT(F8.1,F7.2,F7.3,2F7.1,3F6.3,F6.0)
3010 FORMAT(F8.1,F7.2,F7.3,2F7.1,3F6.3,F6.0,11X,F8.5)
3020 FORMAT(F8.1,F7.2,F7.3,2F7.1,3F6.3,F6.0,F5.2,F6.4)
3030 FORMAT(F8.1,F7.2,F7.3,2F7.1,3F6.3,F6.0,F5.2,F6.4,F8.5)
     END
     SUBROUTINE INFO
     WRITE(*,100)
 100 FORMAT(/' ENTER A NUMBER TO SELECT A FLUID.'/
    *' ANY ENTRY OTHER THAN A NUMBER WILL TERMINATE THE PROGRAM.'/
    *' WHEN THE PROGRAM ASKS FOR A PRESSURE, DENSITY AND TEMPERATURE,'/
    *' ENTER ANY TWO AND A ZERO FOR THE THIRD.  TO SELECT ANOTHER'/
    *' FLUID ENTER ZERO FOR ALL THREE.')
     RETURN
     END
     SUBROUTINE FDATA(IF)
     IMPLICIT REAL*8(A-H)
     IMPLICIT REAL*8(O-Z)
     IMPLICIT INTEGER*4(I-N)
     DIMENSION G(32),VP(9),GV(9),GT(9),FV(4),FT(4),EV(8),ET(8),A(20)
     COMMON/DATA/G,R,GAMMA,VP,DTP,PCC,PTP,TCC,TTP,TUL,TLL,PUL,DCC
     COMMON/SEN/BETA,XO,DELTA,E1,E2,AGAM
     COMMON/CRIT/EM,EOK,RM,TC,DC,X,PC,SIG
     COMMON/SATC/A,DTPV,EG
     COMMON/CPID/GI(11),GH(11),GL(11)
     COMMON/DATA1/GV,GT,FV,FT,EV,ET
     COMMON/ISP/N,NW,NWW
     COMMON/FIXPT/T0,S0,H0
     COMMON/DIEL/BX(6),PX(6)
     COMMON/B/GMW,SEOK,SSIG
     COMMON/A/SE1,G1,B1,DE,BK,D1,XZ,ZZ,X1,X2,X3,X4
     GO TO (3,5,7,1,6,4,8,2,9,10,11,12),IF
   1 WRITE(*,200)
 200 FORMAT(' THE TEMPERATURE RANGE FOR ARGON IS 83.8 TO 400 K'
    1/' (-308.8 TO 260 F) WITH PRESSURES TO 100 MPA (14504 PSIA)')
     OPEN(5,FILE='ARGON.COF')
     N=0
     NW=0
     NWW=0
     GO TO 50
   2 WRITE(*,201)
 201 FORMAT(' THE TEMPERATURE RANGE FOR ETHYLENE IS 104 TO 400 K'
    1/' (-272.4 TO 260 F) WITH PRESSURES TO 40 MPA (5801 PSIA)')
     OPEN(5,FILE='C2H4.COF')
     N=0
     NW=0
     NWW=0
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      NWW=0
      GO TO 50
    3 WRITE(*,202)
  202 FORMAT(' THE TEMPERATURE RANGE FOR HYDROGEN IS 13.8 TO 400 K'
     1/' WITH PRESSURES TO 120 MPA')
      OPEN(5,FILE='PH2.COF')
      N=1
      NW=0
      NWW=0
      GO TO 50
    4 WRITE(*,203)
  203 FORMAT(' THE RANGE OF TEMPERATURE FOR METHANE IS 90.68 TO 600 K'
     1/' WITH PRESSURES TO 200 MPA')
      OPEN(5,FILE='METH.COF')
      N=0
      NW=1
      NWW=0
      GO TO 50
    5 WRITE(*,204)
  204 FORMAT(' THE RANGE OF TEMPERATURE FOR NITROGEN IS 63.15 TO 1900 K'
     1/' WITH PRESSURES TO 1000 MPA')
      OPEN(5,FILE='N2.COF')
      N=0
      NW=0
      NWW=0
      GO TO 50
    6 WRITE(*,205)
  205 FORMAT(' THE RANGE OF TEMPERATURE OFR NITROGEN TRIFLUORIDE IS'
     1,/' 66.36 TO 500 K, WITH PRESSURES TO 50 MPA')
      OPEN(5,FILE='NF3.COF')
      N=0
      NW=0
      NWW=0
      GO TO 50
    7 WRITE(*,206)
  206 FORMAT(' THE RANGE OF TEMPERATURE FOR OXYGEN IS 54.359 TO 400 K'
     1/' WITH PRESSURES TO 120 MPA')
      OPEN(5,FILE='O2.COF')
      N=0
      NW=0
      NWW=0
      GO TO 50
    8 WRITE(*,207)
  207 FORMAT(' THE RANGE OF TEMPERATURE FOR ETHANE IS 90.35 TO 600 K'
     1/' WITH PRESSURES TO 70 MPA')
      OPEN(5,FILE='C2H6.COF')
      N=0
      NW=1
      NWW=0
      GO TO 50
    9 WRITE(*,208)
  208 FORMAT(' THE RANGE OF TEMPERATURE FOR PROPANE IS 85.47 TO 600 K'
     1/' WITH PRESSURES TO 100 MPA')
      OPEN(5,FILE='C3H8.COF')
      N=0
      NW=1
      NWW=0
      GO TO 50
   10 WRITE(*,209)
  209 FORMAT(' THE RANGE OF TEMPERATURE FOR ISO BUTANE IS'
     1/' 113.55 TO 600 K'
     1/' WITH PRESSURES TO 35 MPA')
      OPEN(5,FILE='ISOB.COF')
      N=0
      NW=1
      NWW=0
      GO TO 50
   11 WRITE(*,210)
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210 FORMAT(' THE RANGE OF TEMPERATURE FOR NORMAL BUTANE IS'
   1/' 134.68 TO 500 K'
   1/' WITH PRESSURES TO 70 MPA')
    OPEN(5,FILE='NORB.COF')
    N=0
    NW=1
    NWW=0
    GO TO 50
 12 STOP
 50 READ(5,100)SIG,XO,BETA,DELTA,E1,E2,AGAM
    READ(5,100)EM,EOK,RM,TC,DC,X,PC
100 FORMAT(7E12.6)
    DO 60 I=1,32
 60 READ(5,101)G(I)
101 FORMAT(3D20.13)
    DO 70 I=1,20
 70 READ(5,101)A(I)
    DO 75 I=1,11
 75 READ(5,101)GI(I),GH(I),GL(I)
    DO 80 I=1,9
 80 READ(5,101)VP(I),GV(I),GT(I)
    TCC=VP(8)
    PTP=VP(9)
    TTP=VP(7)
    DO 90 I=1,8
 90 READ(5,101)EV(I),ET(I)
    DO 110 I=1,4
110 READ(5,101)FV(I),FT(I)
    READ(5,101)DTP,DTPV
    READ(5,101)TO,SO,HO
    READ(5,102)R,GAMMA,TUL,TLL,PUL,DCC,PCC
    DO 95  I=1,6
 95 READ(5,101)BX(I),PX(I)
    IF(NW.EQ.0)GO TO 96
    READ(5,100)SE1,G1,B1,DE,BK,D1
    READ(5,100)XZ,ZZ,X1,X2,X3,X4
    READ(5,100)GMW,SEOK,SSIG,EG
    EM=GMW
 96 CONTINUE
    CLOSE(5,STATUS='KEEP')
102 FORMAT(F10.8,E14.8,3F8.2,2F8.4)
    RETURN
    END
    SUBROUTINE LIMITS(P,T,IL)
    IMPLICIT REAL*8(A-H)
    IMPLICIT REAL*8(O-Z)
    IMPLICIT INTEGER*4(I-N)
    DIMENSION G(32),VP(9)
    COMMON/DATA/G,R,GAMMA,VP,DTP,PCC,PTP,TCC,TTP,TUL,TLL,PUL,DCC
    IF(P .GT. PUL)GO TO 10
    IF(T .GT. TUL.OR.T .LT. TLL)GO TO 12
    PM=PMELT(T)
    IF(P .GT. PM) GO TO 20
    IL=1
    RETURN
 10 WRITE(*,11)PUL
 11 FORMAT(' THE INPUT PRESSURE IS OUT OF THE RANGE OF THIS EQUATION '
   1/' THE RANGE FOR THIS EQUATION IS FROM 0 TO ',F6.0,' MPA')
    IL=0
    RETURN
 12 TLLF= (TLL-273.15D0)*1.8D0+32.D0
    TULF= (TUL-273.15D0)*1.8D0+32.D0
    WRITE(*,13) TLL,TUL,TLLF,TULF
 13 FORMAT(' THE INPUT TEMPERATURE IS OUT OF RANGE'
   A /' THE RANGE FOR THIS EQUATION IS  ',F6.2,' K   TO ',F6.0,' K',/,
   B 27X,' OR ',F8.2,' F   TO ',F6.0,' F')
    IL=0
    RETURN
```

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   20 TM=TMELT(P)
      TF=(TM-273.15D0)*1.8D0+32.D0
      WRITE(*,22) TM,TF
   22 FORMAT(' SOLID PHASE DETECTED.',/,' FOR THIS PRESSURE,  TEMP'
     A ' SHOULD EXCEED ',F8.3,' K,  OR',F9.3,' F')
      IL=0
      END
      SUBROUTINE PROPS(PP,DD,TT,K)
      IMPLICIT REAL*8(A-H)
      IMPLICIT REAL*8(O-Z)
      IMPLICIT INTEGER*4(I-N)
C THE 32 TERM EQUATION OF STATE, INPUT IS DENSITY(MOLES/L),
C TEMPERATURE(K), OUTPUT (PP) IS PRESSURE(MPA),OR DP/DD IN
C LITER-MPA/MOLE OR DP/DT MPA/K OR S,H,OR CV AT ONE LIMIT OF
C INTEGRATION
      DIMENSION X(33)
      DIMENSION B(33),G(32),VP(9)
      EQUIVALENCE (B,X)
      COMMON/DATA/G,R,GAMMA,VP,DTP,PCC,PTP,TCC,TTP,TUL,TLL,PUL,DCC
      DATA M/32/
      D=DD
      P=PP
      T=TT
      GM=GAMMA
      D2=D*D
      D3=D2*D
      D4=D3*D
      D5=D4*D
      D6=D5*D
      D7=D6*D
      D8=D7*D
      D9=D8*D
      D10=D9*D
      D11=D10*D
      D12=D11*D
      D13=D12*D
      TS=DSQRT(T)
      T2=T*T
      T3=T2*T
      T4=T3*T
      T5=T4*T
      F=DEXP(GM*D2)
      GO TO (100,200,300,400,500,600),K
C     ENTRY PRESS
  100 B(1)=D2*T
      B(2)=D2*TS
      B(3)=D2
      B(4)=D2/T
      B(5)=D2/T2
      B(6)=D3*T
      B(7)=D3
      B(8)=D3/T
      B(9)=D3/T2
      B(10)=D4*T
      B(11)=D4
      B(12)=D4/T
      B(13)=D5
      B(14)=D6/T
      B(15)=D6/T2
      B(16)=D7/T
      B(17)=D8/T
      B(18)=D8/T2
      B(19)=D9/T2
      B(20)=D3*F/T2
      B(21)=D3*F/T3
      B(22)=D5*F/T2
      B(23)=D5*F/T4
      B(24)=D7*F/T2
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      B(25)=D7*F/T3
      B(26)=D9*F/T2
      B(27)=D9*F/T4
      B(28)=D11*F/T2
      B(29)=D11*F/T3
      B(30)=D13*F/T2
      B(31)=D13*F/T3
      B(32)=D13*F/T4
      P=0
      DO 101 I=1,M
  101 P=P+B(I)*G(I)
      P=P+R*D*T
      PP=P
      RETURN
C     ENTRY DPDD
  200 F1=2.D0*F*GM*D
      F21=3.D0*F*D2 +F1*D3
      F22=5.D0*F*D4 +F1*D5
      F23=7.D0*F*D6 +F1*D7
      F24=9.D0*F*D8 +F1*D9
      F25=11.D0*F*D10+F1*D11
      F26=13.D0*F*D12+F1*D13
      B( 1)=2.D0*D*T
      B( 2)=2.D0*D*TS
      B( 3)=2.D0*D
      B( 4)=2.D0*D/T
      B( 5)=2.D0*D/T2
      B( 6)=3.D0*D2*T
      B( 7)=3.D0*D2
      B( 8)=3.D0*D2/T
      B( 9)=3.D0*D2/T2
      B(10)=4.D0*D3*T
      B(11)=4.D0*D3
      B(12)=4.D0*D3/T
      B(13)=5.D0*D4
      B(14)=6.D0*D5/T
      B(15)=6.D0*D5/T2
      B(16)=7.D0*D6/T
      B(17)=8.D0*D7/T
      B(18)=8.D0*D7/T2
      B(19)=9.D0*D8/T2
      B(20)=F21/T2
      B(21)=F21/T3
      B(22)=F22/T2
      B(23)=F22/T4
      B(24)=F23/T2
      B(25)=F23/T3
      B(26)=F24/T2
      B(27)=F24/T4
      B(28)=F25/T2
      B(29)=F25/T3
      B(30)=F26/T2
      B(31)=F26/T3
      B(32)=F26/T4
      P=0
      DO 201 I=1,M
  201 P=P+B(I)*G(I)
      P=P+R*T
      PP=P
      RETURN
C     ENTRY DPDT
  300 X( 1)=D2
      X( 2)=D2/(2.D0*TS)
      X( 3)=0.D0
      X( 4)=-D2/T2
      X( 5)=-2.D0*D2/T3
      X( 6)=D3
      X( 7)=0.D0
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      X(  8)=-D3/T2
      X(  9)=-2.D0*D3/T3
      X(10)=D4
      X(11)=0.D0
      X(12)=-D4/T2
      X(13)=0.D0
      X(14)=-D6/T2
      X(15)=-2.D0*D6/T3
      X(16)=-D7/T2
      X(17)=-D8/T2
      X(18)=-2.D0*D8/T3
      X(19)=-2.D0*D9/T3
      X(20)=-2.D0*D3*F/T3
      X(21)=-3.D0*D3*F/T4
      X(22)=-2.D0*D5*F/T3
      X(23)=-4.D0*D5*F/T5
      X(24)=-2.D0*D7*F/T3
      X(25)=-3.D0*D7*F/T4
      X(26)=-2.D0*D9*F/T3
      X(27)=-4.D0*D9*F/T5
      X(28)=-2.D0*D11*F/T3
      X(29)=-3.D0*D11*F/T4
      X(30)=-2.D0*D13*F/T3
      X(31)=-3.D0*D13*F/T4
      X(32)=-4.D0*D13*F/T5
      P=0
      DO 301 I=1,M
  301 P=P+G(I)*X(I)
      PP=P+R*D
      RETURN
C     ENTRY DSDN
C     PARTIAL OF ENTROPY WITH
C     RESPECT TO THE G COEFFICIENTS
C     S=S0-R*LOGF(D*R*T/P0)+(DSDN(D)-DSDN(0))*1000.D0 +CPOS(T)
  400 G1=F/(2.D0*GM)
      G2=(F*D2-2.D0*G1)/(2.D0*GM)
      G3=(F*D4-4.D0*G2)/(2.D0*GM)
      G4=(F*D6-6.D0*G3)/(2.D0*GM)
      G5=(F*D8-8.D0*G4)/(2.D0*GM)
      G6=(F*D10-10.D0*G5)/(2.D0*GM)
      X(  1)=-D
      X(  2)=-D/(2.D0*TS)
      X(  3)=0.D0
      X(  4)=+D/T2
      X(  5)=2.D0*D/T3
      X(  6)=-D2/2.D0
      X(  7)=0.D0
      X(  8)=D2/(2.D0*T2)
      X(  9)=D2/T3
      X(10)=-D3/3.D0
      X(11)=0.D0
      X(12)=D3/(3.D0*T2)
      X(13)=0.D0
      X(14)=D5/(5.D0*T2)
      X(15)= 2.D0*D5/(5.D0*T3)
      X(16)=D6/(6.D0*T2)
      X(17)=D7/(7.D0*T2)
      X(18)=2.D0*D7/(7.D0*T3)
      X(19)=D8/(4.D0*T3)
      X(20)=2.D0*G1/T3
      X(21)=3.D0*G1/T4
      X(22)=2.D0*G2/T3
      X(23)=4.D0*G2/T5
      X(24)=2.D0*G3/T3
      X(25)=3.D0*G3/T4
      X(26)=2.D0*G4/T3
      X(27)=4.D0*G4/T5
      X(28)=2.D0*G5/T3
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      X(29)=3.D0*G5/T4
      X(30)=2.D0*G6/T3
      X(31)=3.D0*G6/T4
      X(32)=4.D0*G6/T5
      P=0
      DO 401 I=1,M
  401 P=P+G(I)*X(I)
      PP=P
      RETURN
C     ENTRY DUDN
C     TERMS NEEDED FOR ENTHALPY CALCULATION
C     H=H0+(T*DSDN(D)-DSDN(0))*1000.+(DUDN(D-DUDN(0))*1000.+CPOH(T)
C     +(P/D-R*T)*1000.
  500 G1=F/(2.D0*GM)
      G2=(F*D2-2.D0*G1)/(2.D0*GM)
      G3=(F*D4-4.D0*G2)/(2.D0*GM)
      G4=(F*D6-6.D0*G3)/(2.D0*GM)
      G5=(F*D8-8.D0*G4)/(2.D0*GM)
      G6=(F*D10-10.D0*G5)/(2.D0*GM)
      X( 1)=D*T
      X( 2)=D*TS
      X( 3)=D
      X( 4)=D/T
      X( 5)=D/T2
      X( 6)=D2*T/2.D0
      X( 7)=D2/2.D0
      X( 8)=D2/(2.D0*T)
      X( 9)=D2/(2.D0*T2)
      X(10)=D3*T/3.D0
      X(11)=D3/3.D0
      X(12)=D3/(3.D0*T)
      X(13)=D4/4.D0
      X(14)=D5/(5.D0*T)
      X(15)=D5/(5.D0*T2)
      X(16)=D6/(6.D0*T)
      X(17)=D7/(7.D0*T)
      X(18)=D7/(7.D0*T2)
      X(19)=D8/(8.D0*T2)
      X(20)=G1/T2
      X(21)=G1/T3
      X(22)=G2/T2
      X(23)=G2/T4
      X(24)=G3/T2
      X(25)=G3/T3
      X(26)=G4/T2
      X(27)=G4/T4
      X(28)=G5/T2
      X(29)=G5/T3
      X(30)=G6/T2
      X(31)=G6/T3
      X(32)=G6/T4
      P=0
      DO 501 I=1,M
  501 P=P+G(I)*X(I)
      PP=P
      RETURN
C     ENTRY TDSDT
C     TEMP. TIMES THE PARTIAL OF
C     ENTROPY WITH RESPECT TO TEMP.
C     CV=CV0+(TDSDN(/)-TDSDN(D))*1000.
  600 G1=F/(2.D0*GM)
      G2=(F*D2-2.D0*G1)/(2.D0*GM)
      G3=(F*D4-4.D0*G2)/(2.D0*GM)
      G4=(F*D6-6.D0*G3)/(2.D0*GM)
      G5=(F*D8-8.D0*G4)/(2.D0*GM)
      G6=(F*D10-10.D0*G5)/(2.D0*GM)
      X(1)=0.D0
      X( 2)=-D/(4.D0*TS)
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      X(3)=0.D0
      X( 4)=2.D0*D/T2
      X( 5)=6.D0*D/T3
      X(6)=0.D0
      X(7)=0.D0
      X( 8)=D2/T2
      X( 9)=3.D0*D2/T3
      X(10)=0.D0
      X(11)=0.D0
      X(12)=(2.D0*D3)/(3.D0*T2)
      X(13)=0.D0
      X(14)=(2.D0*D5)/(5.D0*T2)
      X(15)=(6.D0*D5)/(5.D0*T3)
      X(16)=D6/(3.D0*T2)
      X(17)=(2.D0*D7)/(7.D0*T2)
      X(18)=(6.D0*D7)/(7.D0*T3)
      X(19)=(3.D0*D8)/(4.D0*T3)
      X(20)=6.D0*G1/T3
      X(21)=12.D0*G1/T4
      X(22)=6.D0*G2/T3
      X(23)=20.D0*G2/T5
      X(24)=6.D0*G3/T3
      X(25)=12.D0*G3/T4
      X(26)=6.D0*G4/T3
      X(27)=20.D0*G4/T5
      X(28)=6.D0*G5/T3
      X(29)=12.D0*G5/T4
      X(30)=6.D0*G6/T3
      X(31)=12.D0*G6/T4
      X(32)=20.D0*G6/T5
      P=0
      DO 601 I=1,M
  601 P=P+G(I)*X(I)
      PP=P
      END
      DOUBLE PRECISION FUNCTION FINDTV(POBS)
      IMPLICIT REAL*8(A-H)
      IMPLICIT REAL*8(O-Z)
      IMPLICIT INTEGER*4(I-N)
C  ITERATES VAPOR PRESS EQN TO FIND TEMP(K),  FOR INPUT OF PRESS(MPA).
C      GIVEN AN INPUT PRESSURE(MPA)
      COMMON/DATA/G,R,GAMMA,VP,DTP,PCC,PTP,TCC,TTP,TUL,TLL,PUL,DCC
      DIMENSION G(32),VP(9)
      T=VP(8)
      DO 7 I=1,10
      P=VPN(T)
      IF(DABS(P-POBS)-.000001D0*POBS)8,8,6
    6 CONTINUE
      CORR=(POBS-P)/DPDTVP(T,P)
    7 T=T+CORR
    8 CONTINUE
      FINDTV=T
      END
      DOUBLE PRECISION FUNCTION CV(D,T)
      IMPLICIT REAL*8(A-H)
      IMPLICIT REAL*8(O-Z)
      IMPLICIT INTEGER*4(I-N)
C  CALCULATES CV(J/(MOL*K)).   INPUT DENS(MOL/L)  AND TEMP(K).
      DATA R/8.31434D0/
      DD=D
      TT=T
      CALL PROPS(CD,DD,TT,6)
      DD=0.0D0
      CALL PROPS(C0,DD,TT,6)
      CV=CPI(TT,1)+(C0-CD)*1000.D0
      CV=CV-R
      END
      FUNCTION FINDD(P,T)
```

```
      IMPLICIT REAL*8(A-H)
      IMPLICIT REAL*8(O-Z)
      IMPLICIT INTEGER*4(I-N)
      DIMENSION G(32),VP(9)
      COMMON/DATA/G,R,GAMMA,VP,DTP,PCC,PTP,TCC,TTP,TUL,TLL,PUL,DCC
      TT=T
      IF(TT.GT.VP(8)*.99999D0)GO TO 100
      IF( P.GT.VPN(TT))GO TO 101
      DD=SATV(TT)
      GO TO 102
  100 PC=PCC
      X=(1.1D0/(9.D0*PC))*P+.7D0/9.D0
      DD=P/(R*T*X)
      IF(P/PC.GT.2D0.AND.T/VP(8).LT.2.5D0)DD=DTP
      GO TO 102
  101 DD=SATL(TT)
  102 CONTINUE
      DO 10 I=1,50
      IF(DD.LE.0.0D0.OR.DD.GT.50D0)GO TO 11
      CALL PROPS(PP,DD,TT,1)
      IF(PP.LE.0.0D0)GO TO 11
      P2=PP
      IF(DABS (P-P2)-1.D-7*P)20,20,1
    1 CALL PROPS(PP,DD,TT,2)
      DP=PP
      CORR=(P2-P)/DP
      IF(DABS (CORR)-1.D-7*DD)20,20,10
   10 DD=DD-CORR
   11 CALL REGULA(P,DD,T)
   20 FINDD=DD
      END
      SUBROUTINE REGULA(PI,DD,TT)
      IMPLICIT REAL*8(A-H)
      IMPLICIT REAL*8(O-Z)
      IMPLICIT INTEGER*4(I-N)
C  ITERATES EQN OF STATE FOR DENSITY WHEN SUBPROG FINDD FAILS.
      DIMENSION G(32),VP(9)
      COMMON/DATA/G,R,GAMMA,VP,DTP,PCC,PTP,TCC,TTP,TUL,TLL,PUL,DCC
      T=TT
      P=PI
      D2=0.0D0
      IF(T.LT.TCC)GO TO 10
      D0=DCC*TCC/T
      GO TO 20
   10 PP=VPN(T)
      IF(P.GT.PP)GO TO 15
      D0=SATV(T)
      DO 11 I=1,150
      CALL PROPS(P0,D0,T,1)
      IF(P0.GE.P)GO TO 12
   11 D0=D0+.0001D0*D0
      GO TO 42
   12 D1=D0
   13 CALL PROPS(P1,D1,T,1)
      IF(P1.LT.P)GO TO 14
      IF(D1.LE..1D0*PTP)GO TO 42
      D0=D1
      Z=(P1-P)/P
      IF(Z.LT..1D0)Z=.1D0
      IF(Z.GT..9D0)Z=.9D0
      D1=D1-Z*D1
      GO TO 13
   14 CALL PROPS(P0,D0,T,1)
      DO 140 I=1,50
      D=D1
      P3=P1
      IF(DABS(P-P1).LT..00001D0*P)GO TO 40
      P2=P-P1
```

```
      D1=D1+(D1-D0)*P2/(P1-P0)
      IF(DABS(D-D1).LE..00001D0*D)GO TO 40
      IF(DABS(P-P1).LT..005D0*P)D2=FINDM(P,T,D1)
      IF(D2.GT.0.0D0.AND.D2.LT.50.D0)D1=D2
      D2=0.0D0
      CALL PROPS(P1,D1,T,1)
      IF(P0.GT.P.AND.P1.GT.P)GO TO 120
      IF(P0.LT.P.AND.P1.LT.P)GO TO 120
      GO TO 140
  120 P0=P3
      D0=D
  140 CONTINUE
      GO TO 41
   15 D0=SATL(T)
      DO 16 I=1,10
      CALL PROPS(P0,D0,T,1)
      IF(P0.LE.P)GO TO 17
   16 D0=D0-.0001D0*D0
      GO TO 42
   17 D1=D0
   18 CALL PROPS(P1,D1,T,1)
      IF(D1.GE.50.D0)GO TO 42
      IF(P1.GT.P)GO TO 14
      D0=D1
      Z=(P-P1)/P
      Z=Z*10.D0
      IF(T/TCC.LT..6D0)Z=1.D0
      IF(Z.LT.1.D0)Z=1.D0
      IF(Z.GT.9.D0)Z=9.D0
      D1=D1+.01D0*D1*Z
      GO TO 18
   20 CALL PROPS(P0,D0,T,1)
      IF(P.LE.P0)GO TO 30
      D1=D0
   21 CALL PROPS(P1,D1,T,1)
      IF(P1.GE.P)GO TO 14
      IF(D1.GE.50.D0)GO TO 42
      D0=D1
      Z=(P-P1)/P
      Z=Z*10.D0
      IF(Z.LT.1D0)Z=1.D0
      IF(Z.GT.9D0)Z=9.D0
      D1=D1+.1D0*D1*Z
      GO TO 21
   30 D1=D0
   31 CALL PROPS(P1,D1,T,1)
      IF(P1.LE.P)GO TO 14
      IF(D1.LE..1D0*PTP)GO TO 42
      D0=D1
      Z=(P1-P)/P
      Z=Z*10.D0
      IF(Z.LT.1D0)Z=1.D0
      IF(Z.GT.9D0)Z=9.D0
      D1=D1-.1D0*D1*Z
      GO TO 31
   40 DD=D1
      RETURN
   41 WRITE(*,101)P,T,D
  102 FORMAT(' REGULA FAILED AT P=',E11.4,' AND T=',F7.2)
  101 FORMAT(' DENSITY ITERATION FAILED AT P=',F7.2,' AND T=',F7.2,
     1/' DENSITY RETURNED IS',E17.8)
      RETURN
   42 WRITE(*,102)P,T
      END
      DOUBLE PRECISION FUNCTION CP(D,T)
      IMPLICIT REAL*8(A-H)
      IMPLICIT REAL*8(O-Z)
      IMPLICIT INTEGER*4(I-N)
```

```
C  CALCULATES CP(J/(MOL*K)).  INPUT DENS(MOL/L), TEMP(K).
      CVEE=CV(D,T)
      CALL PROPS(DPT,D,T,3)
      CALL PROPS(DPD,D,T,2)
      CP=CVEE+(T/(D**2)*(DPT**2)/DPD)*1000.D0
      END
      DOUBLE PRECISION FUNCTION DPDTVP(TT,P)
      IMPLICIT REAL*8(A-H)
      IMPLICIT REAL*8(O-Z)
      IMPLICIT INTEGER*4(I-N)
C  CALCULATES THE DERIVATIVE OF PRESSURE WITH RESPECT TO TEMPERATURE
C  AT SATURATION.  INPUT IS TEMP(K),  OUTPUT IS DPDT(MPA/K).
      COMMON/DATA/G,R,GAMMA,VP,DTP,PCC,PTP,TCC,TTP,TUL,TLL,PUL,DCC
      DIMENSION G(32),VP(9)
      T=TT
      IF(TT.GT.VP(8))GO TO 1
      X=(1.D0-VP(7)/T)/(1.D0-VP(7)/VP(8))
      DXDT=(VP(7)/T**2)/(1.D0-VP(7)/VP(8))
      DPDT=VP(1)*DXDT+2.D0*VP(2)*X*DXDT+VP(3)*3.D0*X**2*DXDT+VP(5)*
     1((1.D0-X)**VP(6))*DXDT+VP(5)*X*((1.D0-X)**(VP(6)-1.D0))*VP(6)
     2*(-DXDT)
      DPDTVP=DPDT*P
      RETURN
    1 DPDTVP=0.0D0
      END
      DOUBLE PRECISION FUNCTION FINDM(P,T,DD)
      IMPLICIT REAL*8(A-H)
      IMPLICIT REAL*8(O-Z)
      IMPLICIT INTEGER*4(I-N)
C  SOLVES FOR DENSITY(MOL/L) BY ITERATION.  INPUT IS PRESSURE(MPA),
C  TEMPERATURE(K), AND A STARTING VALUE OF DENSITY.  THIS FCN IS AN
C  ALTERNATIVE FOR  FUNCTION FINDD.
      TT=T
      DO 10 I=1,50
      CALL PROPS(PP,DD,TT,1)
      P2=PP
      IF(DABS(P-P2)-1.D-7*P)20,20,1
    1 CALL PROPS(PP,DD,TT,1)
      DP=PP
      CORR=(P2-P)/DP
      D=DD
      IF(DABS(CORR)-1.D-7*D)20,20,10
   10 DD=DD-CORR
      FINDM=0
      RETURN
   20 FINDM=DD
      END
      DOUBLE PRECISION FUNCTION ENTHAL(P,D,T)
      IMPLICIT REAL*8(A-H)
      IMPLICIT REAL*8(O-Z)
      IMPLICIT INTEGER*4(I-N)
      R= .00831434D0
      DD=D
      TT=T
      CALL PROPS(SD,DD,TT,4)
      CALL PROPS(UD,DD,TT,5)
      DD=0.D0
      CALL PROPS(S0,DD,TT,4)
      CALL PROPS(U0,DD,TT,5)
      ENTHAL=T*(SD-S0)*1000.D0+(UD-U0)*1000.D0+CPI(T,3)+(P/D-R*T)*1000.D0
      END
      DOUBLE PRECISION FUNCTION ENTROP(D,T)
      IMPLICIT REAL*8(A-H)
      IMPLICIT REAL*8(O-Z)
      IMPLICIT INTEGER*4(I-N)
C  CALCULATES ENTROPY(J/(MOL-K), FROM INPUT OF DENSITY(MOL/L) AND TEMP(K).
      R=  .00831434D0
      P0=  .101325D0
      DD=D
```

```
      TT=T
      CALL PROPS(SD,DD,TT,4)
      DD=0
      CALL PROPS(SO,DD,TT,4)
      ENTROP=(SD-SO)*1000.D0-R*DLOG(D*R*T/P0)*1000.D0+CPI(T,2)
      END
      DOUBLE PRECISION FUNCTION SATL(TT)
      IMPLICIT REAL*8(A-H)
      IMPLICIT REAL*8(O-Z)
      IMPLICIT INTEGER*4(I-N)
C  CALCULATES DENSITY(MOL/L) OF SATURATED LIQUID.  INPUT IS TEMP(K).
      DIMENSION A(20)
      DIMENSION G(32),VP(9)
      COMMON/DATA/G,R,GAMMA,VP,DTP,PCC,PTP,TCC,TTP,TUL,TLL,PUL,DCC
      COMMON/SATC/A,DTPV,EG
      COMMON/ISP/N,NW,NWW
      IF(NW.EQ.1)GO TO 30
      T=TT
      K=14
      KK=7
   10 IF(T.GE.TCC*.99999D0)GO TO 20
      ITT=TCC
      IF(ITT+1-T.LT.1.D0)T=ITT
      X=(T-TCC)/(TTP-TCC)
      D=A(K)*DLOG(X)
      DO 11 I=2,KK
      K=K+1
      MM=I
      IF(MM.GE.5)MM=MM+1
   11 D=D+A(K)*(1.D0-X**((MM-5)/3.D0))
      IF(K.LT.14)GO TO 12
      D=DCC+DEXP(D)*(DTP-DCC)
      GO TO 13
   12 D=DCC+DEXP(D)*(DTPV-DCC)
   13 SATL=D
      IF(ITT+1-TT.LT.1)SATL=D-(D-DCC)*(TT-T)
      RETURN
   20 SATL=DCC
      RETURN
   30 CALL SSATL(DL,TT)
      SATL=DL
      END
      DOUBLE PRECISION FUNCTION SATV(TT)
      IMPLICIT REAL*8(A-H)
      IMPLICIT REAL*8(O-Z)
      IMPLICIT INTEGER*4(I-N)
C  CALCULATES DENSITY(MOL/L) OF SATURATED VAPOUR.  INPUT IS TEMP(K).
      DIMENSION A(20)
      DIMENSION G(32),VP(9)
      COMMON/DATA/G,R,GAMMA,VP,DTP,PCC,PTP,TCC,TTP,TUL,TLL,PUL,DCC
      COMMON/SATC/A,DTPV1,EG
      COMMON/ISP/N,NW,NWW
      IF(NW.EQ.1)GO TO 30
      K=1
      KK=13
      T=TT
   10 IF(T.GE.TCC*.99999D0)GO TO 20
      ITT=TCC
      IF(ITT+1-T.LT.1.D0)T=ITT
      X=(T-TCC)/(TTP-TCC)
      D=A(K)*DLOG(X)
      DO 11 I=2,KK
      K=K+1
      MM=I
      IF(MM.GE.5)MM=MM+1
   11 D=D+A(K)*(1.D0-X**((MM-5)/3.D0))
      IF(K.LT.14)GO TO 12
      D=DCC+DEXP(D)*(DTP-DCC)
      GO TO 13
```

```
   12 D=DCC+DEXP(D)*(DTPV-DCC)
   13 SATV=D
      IF(ITT+1-TT.LT.1)SATV=D-(D-DCC)*(TT-T)
      RETURN
   20 SATV=DCC
      RETURN
   30 CALL SSATV(DV,TT)
      SATV=DV
      END
      DOUBLE PRECISION FUNCTION SOUND(D,T)
      IMPLICIT REAL*8(A-H)
      IMPLICIT REAL*8(O-Z)
      IMPLICIT INTEGER*2(I-N)
C  CALCULATES SPEED OF SOUND(M/S).  INPUT IS DENSITY(MOL/L) AND TEMP(K).
      COMMON/CRIT/ W, EOK, RM, TC, DC, X , PC, SIG
      CALL PROPS(DP,D,T,2)
      SOUND=((CP(D,T)/CV(D,T))*DP*1000000.D0/W)**.5D0
      END
      DOUBLE PRECISION FUNCTION VISC(DD,T)
      IMPLICIT REAL*8(A-H)
      IMPLICIT REAL*8(O-Z)
      IMPLICIT INTEGER*4(I-N)
C  CALCULATES VISCOSITY(MICRO PA*S).  INPUT IS DENSITY(MOL/L) AND TEMP(K).
      COMMON/CRIT/ GMW, EOK, RM, TC, DC, X , PC, SIG
      COMMON/ISP/N,NW,NWW
      IF(NW.EQ.1)GO TO 10
      D=DD*GMW/1000.D0
      VISC=DILV(T)+FDCV(D,T)+EXCESV(D,T)
      RETURN
   10 VISC=VISCE(DD,T)
      END
      DOUBLE PRECISION FUNCTION THERM(DD,T)
      IMPLICIT REAL*8(A-H)
      IMPLICIT REAL*8(O-Z)
      IMPLICIT INTEGER*4(I-N)
C  RETURNS THERMAL CONDUCTIVITY(W/(M*K)).  INPUT IS DENSITY(MOL/L), TEMP(K).
      COMMON/HAN/CR,TCI
      COMMON/ISP/N,NW,NWW
      COMMON/CRIT/ GMW, EOK, RM, TC, DC, X , PC, SIG
      IF(NW.EQ.1)GO TO 10
      D=DD*GMW/1000.D0
      CR=CRITC(D,T)
      THER=DILT(T)+FDCT(D,T)+EXCEST(D,T)+CR
      TCI=THER-CR
      THERM=THER
      RETURN
   10 THERM=THERME(DD,T)
      END
      DOUBLE PRECISION FUNCTION EXCESV(D,T)
      IMPLICIT REAL*8(A-H)
      IMPLICIT REAL*8(O-Z)
      IMPLICIT INTEGER*4(I-N)
C     CALCULATES EXCESS VISCOSITY
      COMMON/DATA1/GV,GT,FV,FT,EV,ET
      DIMENSION GV(9),GT(9),FV(4),FT(4),EV(8),ET(8)
      R2=D**(.5D0)*((D-EV(8))/EV(8))
      R=D**(.1D0)
      X=EV(1)+EV(2)*R2+EV(3)*R+EV(4)*R2/(T*T)+EV(5)*R/T**(1.5D0)+EV(6)/T
     1+EV(7)*R2/T
      X1=EV(1)+EV(6)/T
      EXCESV= DEXP(X)- DEXP(X1)
      END
      DOUBLE PRECISION FUNCTION EXCEST(D,T)
      IMPLICIT REAL*8(A-H)
      IMPLICIT REAL*8(O-Z)
      IMPLICIT INTEGER*4(I-N)
      COMMON/DATA1/GV,GT,FV,FT,EV,ET
      DIMENSION GV(9),GT(9),FV(4),FT(4),EV(8),ET(8)
C     CALCULATES EXCESS THERMAL CONDUCTIVITY
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```
      R2=D**(.5D0)*((D-ET(8))/ET(8))
      R=D**(.1D0)
      X=ET(1)+ET(2)*R2+ET(3)*R+ET(4)*R2/(T*T)+ET(5)*R/T**(1.5D0)+ET(6)/T
     1+ET(7)*R2/T
      X1=ET(1)+ET(6)/T
      EXCEST= DEXP(X)- DEXP(X1)
      END
      DOUBLE PRECISION FUNCTION FDCV(D,T)
      IMPLICIT REAL*8(A-H)
      IMPLICIT REAL*8(O-Z)
      IMPLICIT INTEGER*4(I-N)
C  FIRST DENSITY CORRECTION FOR VISC.
      COMMON/DATA1/GV,GT,FV,FT,EV,ET
      COMMON/CRIT/ GMW, EOK, RM, TC, DC, X , PC, SIG
      DIMENSION GV(9),GT(9),FV(4),FT(4),EV(8),ET(8)
      FDCV=(FV(1)+FV(2)*(FV(3)-DLOG(T/FV(4)))**2)*D
      END
      DOUBLE PRECISION FUNCTION FDCT(D,T)
      IMPLICIT REAL*8(A-H)
      IMPLICIT REAL*8(O-Z)
      IMPLICIT INTEGER*4(I-N)
C  FIRST DENSITY CORRECTION FOR THERMAL COND.
      COMMON/DATA1/GV,GT,FV,FT,EV,ET
      DIMENSION GV(9),GT(9),FV(4),FT(4),EV(8),ET(8)
      COMMON/CRIT/ GMW, EOK, RM, TC, DC, X , PC, SIG
      FDCT=(FT(1)+FT(2)*(FT(3)-DLOG(T/FT(4)))**2)*D
      END
      FUNCTION CRITC(D,T)
      IMPLICIT REAL*8(A-H)
      IMPLICIT REAL*8(O-Z)
      IMPLICIT INTEGER*4(I-N)
C  CALCULATES CRITICAL ENHANCEMENT FOR THERM. COND.
C  INPUT UNITS ARE G/CC, K,  OUTPUT IS W/(M*K).
      COMMON/CRIT/ GMW, EOK, RM, TC, DC, X , PC, SIG
      COMMON/CHECK/DELD,DELT,DSTAR,TSTAR
      COMMON/HJM/EPSI,CPCV,RRR,AKT
      COMMON/ISP/N,NW,NWW
      AV=6.0225D+23
      BK=1.38054D-16
      DELD=DABS (D-DC)/DC
      DELT=DABS (T-TC)/TC
C  CALCULATE DISTANCE PARAMETER
      R=(RM**2.5D0)*(D**0.5D0)*(AV/GMW)**0.5D0
      R=R*(EOK**0.5D0)*X/(T**0.5D0)
      RRR=R
C   GENERAL  EQUATION
      DX=D*1000.D0/GMW
C  DX IN MOL/L,  D IN G/CM3.
      CALL PROPS(DPT,DX,T,3)
C  DPDT IN MPA/K.
      DPT=DPT*1.0D+7
C  DPDT NOW IN DYNES/(CM2*K)
      CALL PROPS(DPD,DX,T,2)
C  DPDD IN L*MPA/MOL.
      DPD=DPD*1.0D+7*1000./GMW
C  DPDD NOW IN DYNE*CM/G.
      IF( DPD.LT.0.0D0) DPD=1.D0
   94 VIS=VISC(DX,T)*(1.0D-05)
C  VISCOSITY NOW IS G/(CM*S).
      IF(DELD.GT.0.25D0)GO TO 10
    8 IF(DELT.GT.0.025D0)GO TO 10
    9 COMPRES=SENG(D,T)
      GO TO 12
   10 COMPRES=1.D0/(D*DPD)**0.5D0
   12 EX=BK*T**2*(DPT**2)*COMPRES
      EXB=R*((BK*T)**0.5D0)*(D**0.5D0)*((AV/GMW)**0.5D0)
      CRIT=EX/(EXB*6.D0*3.14159D0*VIS)
C   THERMAL COND, CRIT, IS IN ERG/(CM*SEC*K)
C   PUT IN DAMPING FACTOR
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      BDD=((D-DC)/DC)**4
      BTT=((T-TC)/TC)**2
      BXX= -18.66D0*BTT - 4.25D0*BDD
      IF(BXX.LT.-1.D+2) BXX= -1.D+2
      FACT= DEXP( BXX )
C     FACT=DEXP (-18.66D0*BTT - 4.25D0*BDD)
      DELC=CRIT*FACT
      CRITC=DELC/100000.D0
C    THERMAL COND, CRITC, IS NOW IN W/(M*K)
      AKT=COMPRES*COMPRES
      EPSI=R*R*BK*T*(AV*D/GMW)*AKT
      EPSI=EPSI**0.5D0
C    CALC  CP-CV
      CPCV=T*(DPT**2)*AKT/D
      END
      DOUBLE PRECISION FUNCTION SENG(D,T)
      IMPLICIT REAL*8(A-H)
      IMPLICIT REAL*8(O-Z)
      IMPLICIT INTEGER*4(I-N)
C  SCALED EQUATION OF STATE FOR CRITICAL REGION
      COMMON/CRIT/ GMW, EOK, RM, TC, DC, X , PC, SIG
      COMMON/SEN/BETA,XO,DELTA,E1, E2, AGAM
      COMMON/CHECK/DELD,DELT,DSTAR,TSTAR
      DSTAR= D/DC
      TSTAR=T/TC
      BETO=1.D0/BETA
      XX=DELT/DELD**BETO
      AG=AGAM-1.D0
       BET2= 2.0D0*BETA
      AGB=AG/BET2
      DEL1=DELTA-1.D0
       AGBB=(AG-BET2)/BET2
      XXO=(XX+ XO)/XO
      XXB=XXO**BET2
      BRAK=1.D0 + E2*XXB
       BRAK1=BRAK**AGB
      H=E1*XXO*BRAK1
      HPRIM=(E1/XO)*BRAK1 + (AG/XO)*E1*E2*(XXB)*(BRAK**AGBB)
      RCOM=(DELD**DEL1)*(DELTA*H - (XX/BETA)*HPRIM  )
      RCOMP=1.D0/(RCOM*DSTAR**2)
      RCM=RCOMP/(PC*1.0D+7)
C  RCM IN CM2/DYNE, PC IN MPA
      RCM=RCM**0.5D0
       SENG=RCM
      END
      DOUBLE PRECISION FUNCTION DILV(T)
      IMPLICIT REAL*8(A-H)
      IMPLICIT REAL*8(O-Z)
      IMPLICIT INTEGER*4(I-N)
C  DILUTE GAS VISCOSITY
      COMMON/DATA1/GV,GT,FV,FT,EV,ET
      DIMENSION GV(9),GT(9),FV(4),FT(4),EV(8),ET(8)
      SUM=0.0D0
      TF=T**(1.D0/3.D0)
      TFF=T**(-4.D0/3.D0)
      DO 10 I=1,9
      TFF=TFF*TF
   10 SUM=SUM+GV(I)*TFF
      DILV=SUM
      END
      DOUBLE PRECISION FUNCTION DILT(T)
      IMPLICIT REAL*8(A-H)
      IMPLICIT REAL*8(O-Z)
      IMPLICIT INTEGER*4(I-N)
C  DILUTE GAS THERMAL CONDUCTIVITY.
      COMMON/DATA1/GV,GT,FV,FT,EV,ET
      DIMENSION GV(9),GT(9),FV(4),FT(4),EV(8),ET(8)
      TF=T**(1.D0/3.D0)
      TFF=T**(-4.D0/3.D0)
```

```
      SUM=0
      DO 20 I=1,9
      TFF=TFF*TF
   20 SUM=SUM+GT(I)*TFF
      DILT=SUM
      END
      DOUBLE PRECISION FUNCTION FINDP(D,T)
      IMPLICIT REAL*8(A-H)
      IMPLICIT REAL*8(O-Z)
      IMPLICIT INTEGER*4(I-N)
      DIMENSION G(32),VP(9)
      COMMON/DATA/G,R,GAMMA,VP,DTP,PCC,PTP,TCC,TTP,TUL,TLL,PUL,DCC
      DD=D
      TT=T
      IF(TT.LT.TCC)GO TO 10
    1 CALL PROPS(PP,DD,TT,1)
      FINDP=PP
      RETURN
   10 P=VPN(TT)
      DV=FINDD(P-.0001D0,TT)
      DL=FINDD(P+.0001D0,TT)
      IF(DD.LE.DV.OR.DD.GE.DL)GO TO 1
      WRITE(*,100)DV,DL,DD
      CALL PROPS(PP,DV,TT,1)
      FINDP=PP
      D=DV
  100 FORMAT(' THE STATE POINT YOU HAVE SPECIFIED CORRESPONDS TO A '
     1/' DENSITY IN THE LIQUID VAPOR COEXISTENCE REGION'
     2/' THE DENSITY OF THE SATURATED VAPOR IS ',F6.4,' MOLES/LITER'
     3/' THE DENSITY OF THE SATURATED LIQUID IS ',F8.4,' MOLES/LITER'
     4/' AND THE INPUT DENSITY IS ',F8.4,' MOLES/LITER'
     5/' SATURATED VAPOR IS ASSUMED')
      END
      DOUBLE PRECISION FUNCTION FINDT(P,D)
      IMPLICIT REAL*8(A-H)
      IMPLICIT REAL*8(O-Z)
      IMPLICIT INTEGER*4(I-N)
C  RETURNS TEMPERATURE(K), FROM THE 32-TERM MBWR EQN OF STATE.
C  INPUT IS PRESSURE(MPA) AND DENSITY(MOL/L).
      DIMENSION G(32),VP(9)
      COMMON/DATA/G,R,GAMMA,VP,DTP,PCC,PTP,TCC,TTP,TUL,TLL,PUL.DCC
      PP=P
      DD=D
      IF(P.GE.PCC)GO TO 1
      TSAT=FINDTV(PP)
      DV=FINDD(PP-.00001D0,TSAT)
      DL=FINDD(PP+.0001D0,TSAT)
      IF(DD.GT.DV.AND.DD.LT.DL)GO TO 30
      TT=TSAT
      GO TO 2
    1 TT=TCC
    2 DO 10 I=1,10
      CALL PROPS(P2,DD,TT,1)
      IF(DABS(PP-P2)-1.D-7*PP)20,20,11
   11 CALL PROPS(DP,DD,TT,3)
      CORR=(P2-PP)/DP
      IF(DABS(CORR)-1.D-5)20,20,10
   10 TT=TT-CORR
   20 FINDT=TT
      RETURN
   30 FINDT=TSAT
      D=DV
      WRITE(*,100)DV,DL,DD
  100 FORMAT(' THE STATE POINT YOU HAVE SPECIFIED CORRESPONDS TO'
     1/' A DENSITY IN THE LIQUID VAPOR COEXISTENCE REGION'
     2/' DENSITY OF THE SATURATED VAPOR IS',F8.4,' MOLES/LITER'
     3/' DENSITY OF THE SATURATED LIQUID IS',F8.4,' MOLES/LITER'
     4/' INPUT DENSITY IS',F8.4,' MOLES/LITER'
     5/' SATURATED VAPOR CONDITIONS ARE ASSUMED')
```

```
      END
      DOUBLE PRECISION FUNCTION FDIEL(P,D,T)
      IMPLICIT REAL*8(A-H)
      IMPLICIT REAL*8(O-Z)
      IMPLICIT INTEGER*4(I-N)
C  DIELECTRIC CONSTANT.  INPUT P(MPA), D(MOL/L) AND T(K).
      COMMON/DIEL/BX(6),PX(6)
      COMMON/ISP/N,NW,NWW
      IF(NW.EQ.1)GO TO 1
      CM= BX(1)+ BX(2)*D+ BX(3)*D**2+ BX(4)*D**3+ BX(5)*D+ BX(6)*T
      FDIEL=(1.D0+2.D0*D*CM)/(1.D0-D*CM)
      RETURN
    1 FDIEL=SDIEL(P,D,T)
      END
      DOUBLE PRECISION FUNCTION CPI(T,K)
      IMPLICIT REAL*8(A-H)
      IMPLICIT REAL*8(O-Z)
      IMPLICIT INTEGER*4(I-N)
C  CALCULATES SPECIFIC HEAT, ENTROPY, AND ENTHALPY FOR THE IDEAL GAS.
C  OUTPUT IS IN J/(MOL*K), FOR CP AND S,  AND J/MOL FOR H.
C  HYDROGEN, (N=1), IS TREATED AS A SPECIAL CASE AS THE COEFF. FOR
C  CP ARE IN THREE TEMPERATURE RANGES.  T < 40 K,  40 < T < 140 K,
C  AND T > 140 K.
      COMMON/CPID/G(11),GH(11),GL(11)
      COMMON/ISP/N,NW,NWW
      COMMON/H2/FHI,FSI
      IF(N.NE.1)GO TO 15
      TX1=140.D0
      TX2=40.D0
      DO 110 J=1,11
  110 G(J)=GH(J)
      IF(T.LT.140.D0)GO TO 130
      GO TO 180
  130 CALL SHI(TX1)
      G(10)=G(10)+FHI
      G(11)=G(11)+FSI
      DO 140 J=1,8
  140 G(J)=GL(J)
      CALL SHI(TX1)
      G(10)=G(10)-FHI
      G(11)=G(11)-FSI
      IF(T.LT.40.D0)GO TO 160
      GO TO 180
  160 CALL SHI(TX2)
      G(10)=G(10)+FHI
      G(11)=G(11)+FSI
      DO 170 J=1,8
  170 G(J)=0.0D0
      G(4)=2.5000315D0
      CALL SHI(TX2)
      G(10)=G(10)-FHI
      G(11)=G(11)-FSI
  180 CONTINUE
   15 U=G(9)/T
      EU=DEXP (U)
      TS=1.D0/T**4
      GO TO (20,40,55),K
   20 CPI=G(8)*U*U*EU/(EU-1.D0)**2
      DO 25 I=1,7
      TS=TS*T
   25 CPI=CPI+G(I)*TS
      CPI=CPI*8.31434D0
      RETURN
   40 CPI=G(8)*(U/(EU-1.D0)-DLOG(1.D0-1.D0/EU))
     1-G(1)*TS*T/3.D0-G(2)*TS*T*T/2.D0-G(3)/T+G(4)*DLOG(T)+G(5)*T
     2+G(6)*T*T/2.D0+G(7)*T**3/3.D0
      CPI=CPI*8.31434D0+G(11)
      RETURN
   55 CPI=G(8)*U*T/(EU-1.D0)-G(1)/(2.D0*T*T)-G(2)/T+G(3)*DLOG(T)+G(4)*T
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```
     1+G(5)*T*T/2.D0+G(6)*T**3/3.D0+G(7)*T**4/4.D0
      CPI=CPI*8.31434D0+G(10)
      END
      SUBROUTINE SHI(T)
      IMPLICIT REAL*8(A-H)
      IMPLICIT REAL*8(O-Z)
      IMPLICIT INTEGER*4(I-N)
      COMMON/CPID/G(11),GH(11),GL(11)
      COMMON/H2/FHI,FSI
    1 U=G(9)/T
      EU=DEXP(U)
      GHI=G(8)*U*T/(EU-1.D0)-G(1)/(2.D0*T*T)-G(2)/T+G(3)*DLOG(T)+G(4)*T
     A +G(5)*T*T/2.D0+G(6)*T**3/3.D0+G(7)*T**4/4.D0
      FHI=GHI*8.31434D0
      U=G(9)/T
      EU=DEXP(U)
      TS=1.D0/T**4
      GHS= G(8)*(U/(EU-1.D0)-DLOG(1.D0-1.D0/EU))-
     A G(1)*TS*T/3.D0-G(2)*TS*T*T/2.D0-G(3)/T+G(4)*DLOG(T)+G(5)*T+
     B G(6)*T*T/2.D0+G(7)*T**3/3.D0
      FSI=GHS*8.31434D0
      END
      DOUBLE PRECISION FUNCTION PMELT(T)
      IMPLICIT REAL*8(A-H)
      IMPLICIT REAL*8(O-Z)
      IMPLICIT INTEGER*4(I-N)
C  COMPUTES MELTING PRESSURE(MPA) FOR INPUT TEMPERATURE(K).
      COMMON/DIEL/BX(6),PX(6)
      COMMON/ISP/N,NW,NWW
      IF(N.EQ.1)GO TO 20
   10 PMELT= PX(1)+ PX(2)*T**PX(3)
      RETURN
   20 IF(T.LT.22.D0)GO TO 10
   30 PMELT= PX(4)+ PX(5)*T**PX(6)
      END
      FUNCTION TMELT(P)
      IMPLICIT REAL*8(A-H)
      IMPLICIT REAL*8(O-Z)
      IMPLICIT INTEGER*4(I-N)
C  COMPUTES MELTING TEMPERATURE(K) FOR INPUT PRESSURE(MPA)
      COMMON/DIEL/BX(6),PX(6)
      COMMON/ISP/N,NW,NWW
      IF(N.EQ.1)GO TO 20
   10 TMELT=((P-PX(1))/PX(2))**(1.D0/PX(3))
      RETURN
   20 IF(P.LT.31.64D0)GO TO 10
   30 TMELT=((P-PX(4))/PX(5))**(1.D0/PX(6))
      END
      DOUBLE PRECISION FUNCTION VPN(TT)
      IMPLICIT REAL*8(A-H)
      IMPLICIT REAL*8(O-Z)
      IMPLICIT INTEGER*4(I-N)
C  CALCULATES VAPOR PRESSURE(MPA), INPUT IS TEMP(K).
      DIMENSION G(32),VP(9)
      COMMON/DATA/G,R,GAMMA,VP,DTP,PCC,PTP,TCC,TTP,TUL,TLL,PUL,DCC
      T=TT
      X=(1.D0-VP(7)/T)/(1.D0-VP(7)/VP(8))
      VPN=VP(9)*DEXP (VP(1)*X+VP(2)*X*X+VP(3)*X**3+VP(4)*X**4+VP(5)*X*
     1(1.D0-X)**VP(6))
      END
      SUBROUTINE SSATL(D1,T1)
      IMPLICIT REAL*8(A-H)
      IMPLICIT REAL*8(O-Z)
      IMPLICIT INTEGER*4(I-N)
C             SATURATED LIQUID AND VAPOR DENSITIES.
C             LIQUID DENSITIES ARE FROM R.D. MCCARTY.
C             VAPOR DENSITYES ARE FROM R.D. GOODWIN.
      DIMENSION G(32),VP(9),A(20)
      COMMON/DATA/G,R,GAMMA,VP,DTP,PCC,PTP,TCC,TTP,TUL,TLL,PUL,DCC
```

```
      COMMON/SATC/ A,DTPV,EG
      IF(T1 .GE. TCC) GO TO 20
      X1=(T1-TCC)/(TTP-TCC)
      Y1=A(7)*DLOG(X1)+ A(8)*(1.D0-1.D0/X1)+
     A A(9)*(1.D0-X1**(-2.D0/3.D0))+ A(10)*(1.D0-X1**(-1.D0/3.D0))+
     B A(11)*(1.D0-X1**( 1.D0/3.D0))+ A(12)*(1.D0-X1**( 2.D0/3.D0))+
     C A(13)*(1.D0-X1)
      D1=DCC+ (DTP-DCC)*DEXP(Y1)
      RETURN
   20 D1=DCC
      END
      SUBROUTINE SSATV(D1,T1)
      IMPLICIT REAL*8(A-H)
      IMPLICIT REAL*8(O-Z)
      IMPLICIT INTEGER*4(I-N)
      DIMENSION G(32),VP(9),A(20)
      COMMON/DATA/G,R,GAMMA,VP,DTP,PCC,PTP,TCC,TTP,TUL,TLL,PUL,DCC
      COMMON/SATC/ A,DTPV,EG
      TT=T1
      IF(TT .GE. TCC) GO TO 20
      YN=DLOG(DCC/DTPV)
      X1=(TCC-TT)/(TCC-TTP)
      Z1=TCC*X1/TT
      Y1= A(1)*Z1+ A(2)*X1**EG+ A(3)*X1+ A(4)*X1**(4.D0/3.D0)
     A   +A(5)*X1**(5.D0/3.D0)+ A(6)*X1*X1
      D1=DCC*DEXP(-YN*Y1)
      RETURN
   20 D1=DCC
      END
      DOUBLE PRECISION FUNCTION SDIEL(P,D,T)
      IMPLICIT REAL*8(A-H)
      IMPLICIT REAL*8(O-Z)
      IMPLICIT INTEGER*4(I-N)
C             DIELECTRIC CONSTANT.  INPUT P(MPA), D(MOL/L) AND T(K).
      COMMON/DIEL/BX(6),PX(6)
      COMMON/DATA/G,R,GAMMA,VP,DTP,PCC,PTP,TCC,TTP,TUL,TLL,PUL,DCC
      DIMENSION G(32),VP(9)
      CM= BX(1)+ BX(2)*D+ BX(3)*D**2+ BX(4)*DLOG(1.D0+TCC/T)+
     A BX(5)*P
      SDIEL=(1.D0+2.D0*D*CM)/(1.D0-D*CM)
      END
      DOUBLE PRECISION FUNCTION THERME(DD,TT)
      IMPLICIT REAL*8(A-H)
      IMPLICIT REAL*8(O-Z)
      IMPLICIT INTEGER*4(I-N)
C             THERMAL CONDUCTIVITY W/(M*K).
      DIMENSION GV(9),GT(9),FV(4),FT(4),EV(8),ET(8)
      COMMON/DATA1/GV,GT,FV,FT,EV,ET
         TI   = 1.D0/TT
         TRM0= ET(1)+ ET(2)*TI+ ET(3)*TI*TI
         TRM1= ET(4)+ ET(5)*TI+ ET(6)*TI*TI
         TRM2= ET(7)+ ET(8)*TI
      BACKG  = TCOND0(TT)+(TRM0+TRM1*DD)*DD/(1.D0+TRM2*DD)
      THERME = BACKG + TCRIT(DD,TT)
      END
      DOUBLE PRECISION FUNCTION TCOND0(TT)
      IMPLICIT REAL*8(A-H)
      IMPLICIT REAL*8(O-Z)
      IMPLICIT INTEGER*4(I-N)
C             THERMAL CONDUCTIVITY (W/(M*K)), TT(K).
C             LOW DENSITY LIMIT.
      DIMENSION GV(9),GT(9),FV(4),FT(4),EV(8),ET(8)
      COMMON/DATA1/GV,GT,FV,FT,EV,ET
      COMMON/B/ GMW,EOK,SIG
C             R IS GAS CONSTANT IN J/(MOL*K).
      R= 8.31434D0
      CON1= 15.D0*R/4.D0
      CON2= 2.D0*CON1/3.D0
      CP0= CPI(TT,1)
```

```
C             CPO IS SPECIFIC HEAT IN J/(MOL*K),
C             VSCTYO IS VISCOSITY IN MICRO-PA*S.
      ETAO    = VSCTYO(TT,0.0D0)/1000000.D0
      TS      = TT/EOK
      YC      = (GT(1)+ GT(2)/TS)*(CPO- CON2)
      TCONDO = 1000.D0*ETAO*(CON1+ YC)/GMW
C             FACTOR OF 1000 CONVERTS G/MOL TO KG/MOL.
      END
      DOUBLE PRECISION FUNCTION TCRIT(DD,TT)
C             CRITICAL ENHANCEMENT W/(M*K), INPUT MOL/L AND K.
      IMPLICIT REAL*8(A-H)
      IMPLICIT REAL*8(O-Z)
      IMPLICIT INTEGER*4(I-N)
      DIMENSION G(32),VP(9)
      COMMON/DATA/G,R,GAMMA,VP,DTP,PCC,PTP,TCC,TTP,TUL,TLL,PUL,DCC
      COMMON/A/ E1,G1,B1,DE,BK,D1,XZ,ZZ,X1,X2,X3,X4
      COMMON/B/ GMW,EOK,SIG
      PC1=PCC*1.D+6
      DELD=DABS(DD-DCC)/DCC
      DELT=DABS(TT-TCC)/TCC
      FACT= X1*DELT**4.D0 + X2*DELD**4.D0
      IF(FACT  .GT.  100.D0) FACT=100.D0
      DFACT=DEXP(-FACT)
      RSTAR=DD/DCC
C             CONVERTING MICRO-PA*S TO PA*S.
      VIS= 1.0D-06*VISCE(DD,TT)
      CALL PROPS(DPD,DD,TT,2)
C             CONVERTING M-PA TO PA.
      DPD=DPD*1.D+6
      CALL PROPS(DPT,DD,TT,3)
      DPT=DPT*1.D+6
      IF(DELD .NE. 0.0D0)GO TO 20
C             CRITICAL ISOCHORE.
   10 BGAM=XZ**G1/D1*((1.D0+E1)/E1)**((G1-1.D0)/(2.D0*B1))
      CHISTAR=BGAM*(DELT)**(-G1)
      GO TO 50
   20 IF(DELD .LE. 0.25D0.AND.DELT .LT. 0.03D0) GO TO 30
      GO TO 40
C             CRITICAL REGION
   30 XX=DELT/DELD**(1.D0/B1)
      Y=(XX+XZ)/XZ
      TOP=DELD**(-G1/B1)*((1.D0+E1)/(1.D0+E1*Y**(2.D0*B1)))**((G1-1.D0
     1)/(2.D0*B1))
      DIV=D1*(DE+(Y-1.D0)*(DE-1.D0/B1+E1*Y**(2.D0*B1))/(1.D0+E1*Y**(2.
     1D0*B1)))
      CHISTAR=TOP/DIV
      GO TO 50
C             NON CRITICAL REGION
   40 CHISTAR=PC1*DD/(DCC**2*DPD)
   50 CHI=CHISTAR**X3
      UPPER=X4*BK/PC1*(TT*DPT/RSTAR)**2*CHI*DFACT
      SSENG=UPPER/(ZZ*6.D0*3.14159D0*VIS)
      TCRIT=SSENG
      END
      DOUBLE PRECISION FUNCTION VISCE(DS,TS)
      IMPLICIT REAL*8(A-H)
      IMPLICIT REAL*8(O-Z)
      IMPLICIT INTEGER*4(I-N)
      DIMENSION G(32),VP(9)
      DIMENSION GV(9),GT(9),FV(4),FT(4),EV(8),ET(8)
      COMMON/DATA1/GV,GT,FV,FT,EV,ET
      COMMON/DATA/G,R,GAMMA,VP,DTP,PCC,PTP,TCC,TTP,TUL,TLL,PUL,DCC
      ETAO= VSCTYO(TS,DS)
      TRM1= EV(3) + EV(4)*TS**(-3.D0/2.D0)
      TRM2= EV(5) + EV(6)/TS + EV(7)*TS**(-2.D0)
      TRMX= DEXP(EV(1) + EV(2)/TS)
      R1   = DS**0.1D0
      R2   = ((DS-DCC)/DCC)*DS**0.5D0
      VISCE = TRMX*(DEXP(TRM1*R1 + TRM2*R2) - 1.D0) + ETAO
```

```
      END
      DOUBLE PRECISION FUNCTION VSCTYO(TX,DX)
C             VISCOSITY THROUGH LINEAR TERM IN DENSITY IN MICRO-PA*S.
C             DENSITY IS IN MOL/L,  AND TEMP IN K.
      IMPLICIT REAL*8(A-H)
      IMPLICIT REAL*8(O-Z)
      IMPLICIT INTEGER*4(I-N)
      DIMENSION CO(9)
      DIMENSION GV(9),GT(9),FV(4),FT(4),EV(8),ET(8)
      COMMON/DATA1/GV,GT,FV,FT,EV,ET
      COMMON/B/ GMW,EOK,SIG
      DATA CO/-3.0328138281D+00, 1.6918880086D+01,-3.7189364917D+01,
     *         4.1288861858D+01,-2.4615921140D+01, 8.9488430959D+00,
     *        -1.8739245042D+00, 2.0966101390D-01,-9.6570437074D-03/
      TS = TX / EOK
      TY = 1.DO / TS
      TZ= TS**(1.DO/3.DO)
      EO=0.DO
         DO 200 J=1,9
         EO=EO+CO(J)*TY
  200    TY=TY*TZ
      OM22 = 1.DO / EO
C             ETAO IS VISCOSITY AT THE LOW DENSITY LIMIT.
      ETAO = 2.6693DO *DSQRT(GMW * TX) / (SIG*SIG * OM22)
      ETA1= FV(1) + FV(2)*(FV(3)-DLOG(TX/FV(4)))**2
      VSCTYO=(ETAO+ETA1*DX)
      END
```

ARGON.COF

```
      .329700E+01 .183000E+00 .355000E+00 .435200E+01 .227000E+01 .287000E+00 .11
   9000E+01
    .399480E+02 .152800E+03 .366900E-07 .150725E+03 .533000E+00 .171240E+01 .486190
   E+01
    -.6569731294000D-04
     .1822957801000D-01
    -.3649470141000D+00
     .1232012107000D+02
    -.8613578274000D+03
     .7978579691000D-05
    -.2911489110000D-02
     .7581821758000D+00
     .8780488169000D+03
     .1423145989000D-07
     .1674146131000D-03
    -.3200447909000D-01
     .2561766372000D-05
    -.5475934941000D-04
    -.4505032058000D-01
     .2013254653000D-05
    -.1678941273000D-07
     .4207329271000D-04
    -.5444212996000D-06
    -.8004855011000D+03
    -.1319304201000D+05
    -.4954923930000D+01
     .8092132177000D+04
    -.9870104061000D-02
     .2020441562000D+00
    -.1637417205000D-04
    -.7038944136000D-01
    -.1154324539000D-07
     .1555990117000D-05
    -.1492178536000D-10
    -.1001356071000D-08
     .2933963216000D-07
    -.2702629237770D+02
     .1310402418660D+00
    -.2674864381280D+01
     .3001768044060D+02
    -.8758991493260D+02
    -.4082674364560D+02
     .1042680664510D+03
    -.6712785553790D+02
     .1510029357010D+02
    -.3312435366370D+02
     .6331462125810D+02
    -.4271497068990D+02
     .1005999000300D+02
     .1376820849000D+02
    -.6646303631910D-01
     .1333687827300D+01
    -.1443714632440D+02
     .6019384720000D+02
    -.2308884638870D+02
     .4653183588870D+01
    0.                      0.                      0.
    0.                      0.                      0.
    0.                      0.                      0.
     .2500000000000D+01 0.                      0.
    0.                      0.                      0.
    0.                      0.                      0.
    0.                      0.                      0.
    0.                      0.                      0.
     .2500000000000D+01 0.                      0.
```

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-.8011774999613D+00 0.                    0.
 .3630410930969D+02 0.                    0.
 .3415111551900D+01  .6114547278700D+04  .6277770374200D+01
 .1191081251900D+01 -.1039439031200D+05 -.9609637663700D+01
-.3407632334000D+00  .6759461461900D+04  .5888754919100D+01
0.                   -.2253650938000D+04 -.1892092632000D+01
 .8955585525100D+00  .4259395013800D+03  .3488657143700D+00
 .1500000000000D+01 -.4725267109300D+02 -.3801678619300D-01
 .8380000000000D+02  .3179527542500D+01  .2520728316700D-02
 .1508600000000D+03 -.1162908378000D+00 -.9109874447800D-04
 .6890606625000D-01  .1804301059200D-02  .1399084294200D-05
-.1231357908600D+02 -.3332702733200D+02
 .2069468571200D+00 0.
 .1602914512200D+02  .3069485997100D+02
 .1171746135100D+04 0.
-.5699589878000D+03  .2295655167400D+04
 .4013607193300D+02 -.3555941584800D+03
 .3987012240300D+02 0.
 .5370000000000D+00  .1000000000000D+01
 .1465365243300D+00  .2414210327000D-01
-.7748742496500D-01  .7569623425500D-02
 .1400000000000D+01  .1000000000000D+01
 .1528000000000D+03  .1528000000000D+03
 .3540027619188D+02  .1029227022329D+00
 .2981500000000D+03  .1547335000000D+03  .6196500000000D+04
.00831434-.55542372E-02  400.00   83.80  100.00 13.4100  4.9058
0.                   -.2105621650000D+03
0.                    .1777605270000D+00
0.                    .1598178680000D+01
0.                   0.
0.                   0.
0.                   0.
```

PH2.COF

```
0.          0.          0.          0.          0.          0.          0.
.201594E+010.          0.          0.          0.          .171240E+010.
 .4675528393416D-04
 .4289274251454D-02
-.5164085596504D-01
 .2961790279801D+00
-.3027194968412D+01
 .1908100320379D-05
-.1339776859288D-03
 .3056473115421D-01
 .5161197159532D+01
 .1999981550224D-07
 .2896367059356D-04
-.2257803939041D-02
-.2287392761826D-06
 .2446261478645D-05
-.1718181601119D-03
-.5465142603459D-07
 .4051941401315D-09
 .1157595123961D-06
-.1269162728389D-08
-.4983023605519D+01
-.1606676092098D+02
-.1926799185310D-01
 .9319894638928D+00
-.3222596554434D-04
 .1206839307669D-03
-.3841588197470D-07
-.4036157453608D-05
-.1250868123513D-10
 .1976107321888D-09
-.2411883474011D-13
-.4127551498251D-13
```

```
 .8917972883610D-12
 .9166177201870D+02
-.1794925244460D+00
 .4546711583950D+01
-.6584995897880D+02
 .7344668045350D+03
-.6825010451750D+03
 .6317836747100D+03
-.5394088732820D+03
 .4309238117830D+03
-.3002957388110D+03
 .1565671653460D+03
-.5041036082250D+02
 .7207069265140D+01
-.1239444403180D+03
 .1403348001420D+01
-.2110238043130D+02
 .1732546228170D+03
-.4442945808710D+03
 .1386993653550D+03
-.2357741610150D+02
 .5262185164597D+08  .5262185164597D+08  .2905965792270D+06
-.1487906248823D+07 -.1487906248823D+07 -.2831103639248D+05
 .1601391392264D+05  .1601391392264D+05  .1050424877391D+04
-.8031235938946D+02 -.8031235938946D+02 -.1535751501769D+02
 .2307407941873D+00  .2307407941873D+00  .1218941696566D+00
-.3176386248370D-03 -.3176386248370D-03 -.2599406479908D-04
 .1643857271214D-06  .1643857271214D-06 -.1288757333406D-05
 .9230816464058D+01  .9230816464058D+01  .1717441975231D+06
 .3000000000000D+04  .3000000000000D+04  .3000000000000D+04
-.6547883783722D+06 -.6547883783722D+06 -.6547883783722D+06
0.                   .3850717781962D+04  .3850717781962D+04
 .3053001341640D+01 0.                   0.
 .2808109258130D+01 0.                   0.
-.6554612165670D+00 0.                   0.
0.                  0.                   0.
 .1595144393740D+01 0.                   0.
 .1581445442800D+01 0.                   0.
 .1380000000000D+02 0.                   0.
 .3293800000000D+02 0.                   0.
 .7042087500000D-02 0.                   0.
0.                  0.
0.                  0.
0.                  0.
0.                  0.
0.                  0.
0.                  0.
0.                  0.
0.                  0.
0.                  0.
0.                  0.
0.                  0.
 .3821428945438D+02  .6322296353698D-01
0.                  0.                   0.
.00831434-.41000000E-02  400.00   13.80  120.00 15.5560  1.2838
 .2024544300000D-02 -.2128148439500D+02
 .3717183200000D-06  .1257466430000D+00
-.9208501300000D-08  .1955000000000D+01
-.3406532800000D-11 -.2652891150000D+02
0.                   .2485785960000D+00
0.                   .1764739000000D+01
```

N2.COF

```
   .354000E+01 .164000E+00 .355000E+00 .435200E+01 .217000E+01 .287000E+00 .119000
  E+01
   .280160E+02 .118000E+03 .393300E-07 .126240E+03 .313900E+00 .167108E+01 .344300
  E+01
    .1380297474657D-03
    .1084506501349D-01
   -.2471324064362D+00
    .3455257980807D+01
   -.4279707690666D+03
    .1064911566998D-04
   -.1140867079735D-02
    .1444902497287D-04
    .1871457567553D+04
    .8218876886831D-08
    .2360990493348D-03
   -.5144803081201D-01
    .4914545013668D-05
   -.1151627162399D-03
   -.7168037246650D-01
    .7616667619500D-05
   -.1130930066213D-06
    .3736831166831D-04
   -.2039851507581D-06
   -.1719662008990D+04
   -.1213055199748D+05
   -.9881399141428D+01
    .5619886893511D+04
   -.1823043964118D-01
   -.2599826498477D+00
   -.4191893423157D-04
   -.2596406670530D-01
   -.1258683201921D-07
    .1049286599400D-05
   -.5458369305152D-10
   -.7674511670597D-09
    .5931232870994D-08
   -.1584534655070D+02
    .4191369114230D-01
   -.1019653716600D+01
    .1347637437990D+02
   -.1099303990870D+03
    .9255188354970D+02
   -.9562338313200D+02
    .1001043667100D+03
   -.7018579373980D+02
    .9000769986470D+01
    .2869811203470D+02
   -.2167676017800D+02
    .4965582264710D+01
    .2183079284770D+02
   -.1264933098070D+00
    .2415441886330D+01
   -.2452568717940D+02
    .9359252071240D+02
   -.3609382516320D+02
    .7574532719890D+01
   -.7352104011573D+03 0.                    0.
    .3422399804120D+02 0.                    0.
   -.5576482845676D+00 0.                    0.
    .3504042283088D+01 0.                    0.
   -.1733901850810D-04 0.                    0.
    .1746508497665D-07 0.                    0.
   -.3568920335443D-11 0.                    0.
    .1005387228088D+01 0.                    0.
    .3353406100000D+04 0.                    0.
    .1491235932073D+02 0.                    0.
```

```
 .2553079069000D+02 0.                    0.
 .5111319209400D+01 -.1822424000000D+05 -.2002957397200D+02
 .6482667539000D+00  .1991532737400D+05  .4976574668400D+01
-.1510873091600D+00 -.9154232449400D+04  .8018895937800D+01
0.                   .2325548405900D+04 -.5502271688800D+01
 .7402849334200D+00 -.3630721422800D+03  .1536373896500D+01
 .1500000000000D+01  .3645750681100D+02 -.2297473725700D+00
 .6315000000000D+02 -.2226188081700D+01  .1936054734600D-01
 .1262600000000D+03  .7805390489500D-01 -.8567738576800D-03
 .1246297500000D-01 -.1189402910400D-02  .1556467093500D-04
-.1212815412900D+02 -.3861329162700D+02
 .5715609213900D+00 0.
 .1609461114800D+02  .3720174333300D+02
 .3695408615800D+04 0.
-.8088980118000D+03 -.3901350907900D+02
 .6846443564000D+02 -.3182610948500D+02
-.2124113591200D+01 0.
 .3150000000000D+00  .1000000000000D+01
-.1121773962300D+00  .5387566663700D-01
 .3291231724400D-01  .6102791110400D-02
 .1400000000000D+01  .1200000000000D+01
 .1180000000000D+03  .1180000000000D+03
 .3097717741477D+02  .2428220857100D-01
0.                   0.                    0.
.00831411-.56000000E-02 1900.00   63.15 1000.00 11.2100  3.3991
 .4399383600000D-02 -.1600002810000D+03
 .1893209600000D-05  .9385755020000D-01
0.                   .1795000000000D+01
-.3145017800000D-08 0.
-.2859270300000D-06 0.
-.4466603400000D-07 0.
```

02. COF

```
 .343700E+01 .183000E+00 .355000E+00 .435200E+01 .221000E+01 .287000E+00 .119000
E+01
 .319988E+02 .113000E+03 .388960E-07 .154575E+03 .436200E+00 .221064E+01 .504290
E+01
 -.4365859650000D-04
  .2005820677000D-01
 -.4197909916000D+00
  .1878215317000D+02
 -.1287473398000D+04
  .1556745888000D-05
  .1343639359000D-03
 -.2228415518000D+00
  .4767792275000D+03
  .4790846641000D-07
  .2462611107000D-03
 -.1921891680000D-01
 -.6978320847000D-06
 -.6214145909000D-04
 -.1860852567000D-01
  .2609791417000D-05
 -.2447611408000D-07
  .1457743352000D-04
 -.1726492873000D-06
 -.2384892520000D+03
 -.2301807796000D+05
 -.2790303526000D+01
  .9400577575000D+04
 -.4169449637000D-02
  .2008497853000D+00
 -.1256076520000D-04
 -.6406362964000D-01
 -.2475580168000D-08
  .1346309703000D-05
 -.1161502470000D-10
```

```
-.1034699798000D-08
 .2365936964000D-07
 .5813947530760D+02
-.4902411961330D-01
 .1683288932520D+01
-.3251612233980D+02
 .5503009898720D+03
-.5109685061150D+03
 .3150915590490D+03
-.2325666592580D+02
-.4884254793590D+02
-.1506242175230D+03
 .2804416038510D+03
-.1766938968610D+03
 .4032477474490D+02
 .2521986883650D+01
-.1360983164720D-01
 .2823161594030D+00
-.2866459053410D+01
 .6170242122840D+01
-.8102207954620D+00
-.2796010689690D+00
-.4981998537119D+04 0.                    0.
 .2302477799952D+03 0.                    0.
-.3455653235107D+01 0.                    0.
 .3521876773671D+01 0.                    0.
-.4354202160244D-04 0.                    0.
 .1346353450132D-07 0.                    0.
 .1620598259591D-10 0.                    0.
 .1031468515726D+01 0.                    0.
 .2239181050000D+04 0.                    0.
 .1238529263264D+03 0.                    0.
 .3816718907989D+02 0.                    0.
 .7568956000000D+01 -.9707637859300D+04 -.2039505219300D+03
 .5004836000000D+01  .8280125420100D+04  .2408814170900D+03
-.2137460000000D+01 -.2466875880300D+04 -.1201417518300D+03
0.                   .2132436024300D+03  .3295494919000D+02
 .3454481000000D+01  .3785104952200D+02 -.5424423959800D+01
 .1514000000000D+01 -.1048721609000D+02  .5473486554000D+00
 .5435900000000D+02  .1113444130400D+01 -.3285482153900D-01
 .1545810000000D+03 -.5367609375700D-01  .1075357210300D-02
 .1479953000000D-03  .1027937964100D-02 -.1461098682000D-04
-.1445497211000D+02 -.2152074113700D+02
-.3142172899400D+00 0.
 .1820116146800D+02  .1679950426100D+02
 .2739042952500D+03 0.
-.2749895694800D+04 -.2994487872100D+04
 .2434068966700D+03  .4735050878800D+03
 .1191150410400D+03 0.
 .4350000000000D+00  .1000000000000D+01
 .4352651515300D+00  .3060000000000D-01
-.2036126387800D+00  .2785000000000D-01
 .1400000000000D+01  .1120000000000D+01
 .1000000000000D+03  .1000000000000D+03
 .4081997364372D+02  .3318894767078D-03
0.                   0.                  0.
.00831411-.56000000E-02 1500.00   54.36  120.00 13.6300  5.0430
 .3960810000000D-02 -.2672268540000D+03
 .2970000000000D-06  .2276063480000D+00
-.4130000000000D-07  .1769000000000D+01
0.                   0.
0.                   0.
-.2140000000000D-07 0.
```

NF3.COF

```
  0.          0.          0.          0.          0.          0.          0.
   .710190E+020.          0.           .234000E+03 .792000E+01 .171240E+010.
    .1774353868000D-02
   -.5409379418000D-01
    .3976634466000D+00
   -.5209476694000D+02
   -.3286322888000D+04
   -.5990517411000D-04
    .9217525601000D-01
   -.4848977075000D+02
   -.4235892691000D+06
   -.9824248063000D-06
    .5432235989000D-02
   -.1462388500000D+01
   -.3366180440000D-03
    .2801374599000D-01
    .8435288597000D+00
   -.1324421452000D-02
    .1875604377000D-04
    .2959643991000D-01
   -.7009976870000D-03
    .4365820912000D+06
   -.1111397536000D+07
    .2411866612000D+04
    .3179136276000D+06
    .6166849090000D+01
    .4260854720000D+01
    .1090598789000D-01
   -.3340951059000D+01
    .8597429644000D-05
    .1240544214000D-03
    .1286224248000D-07
   -.8941104276000D-07
    .3353054595000D-05
    .1312851816360D+03
   -.2269985555360D+01
    .3847083894980D+02
   -.3098272682390D+03
   -.6353485266350D+03
    .9269790283570D+03
    .3714980112590D+03
   -.1822916544700D+04
    .1055924038530D+04
    .1216738953440D+04
   -.2072089283230D+04
    .1134633947100D+04
   -.2266421371400D+03
    .1050872951730D+01
   -.1316864742460D-02
    .3901413319000D-01
   -.5877965979750D+00
    .4009005210170D+01
   -.2033853869770D+01
    .4004343644240D+00
    .7427518245951D+06 0.          0.
   -.4389825372134D+05 0.          0.
    .1012629224351D+04 0.          0.
   -.7140693612211D+01 0.          0.
    .5481339146452D-01 0.          0.
   -.7677196006769D-04 0.          0.
    .4203630864340D-07 0.          0.
   -.6328752997967D+00 0.          0.
    .3000000000000D+04 0.          0.
   -.3493688822979D+05 0.          0.
    .5145589888845D+03 0.          0.
```

```
 .1159387949200D+02 0.                    0.
 .9654850231200D+01 0.                    0.
-.2872773281500D+01 0.                    0.
-.1379770070000D+01 0.                    0.
 .7311244167300D+01 0.                    0.
 .1500000000000D+01 0.                    0.
 .6636000000000D+02 0.                    0.
 .2340000000000D+03 0.                    0.
 .1853782700000D-06 0.                    0.
0.                  0.
0.                  0.
0.                  0.
0.                  0.
0.                  0.
0.                  0.
0.                  0.
0.                  0.
0.                  0.
0.                  0.
0.                  0.
 .2632000000000D+02  .3361200000000D-08
0.                  0.                    0.
.00831441-.56000000E-02  500.00   66.36   50.00  7.9200  4.4607
0.                  -.1909399710000D+03
0.                   .8137501940000D-01
0.                   .1850000000000D+01
0.                  0.
0.                  0.
0.                  0.
```

METH. COF

```
0.          0.          0.          0.          0.          0.          0.
0.          0.          0.          0.          0.          0.          0.
  .9898937956000D-05
  .2199608275000D-01
 -.5322788000000D+00
  .2021657962000D+02
 -.2234398926000D+04
  .1067940280000D-04
  .1457922469000D-03
 -.9265816666000D+00
  .2915364732000D+03
  .2313546209000D-06
  .1387214274000D-03
  .4780467451000D-02
  .1176103833000D-04
 -.1982096730000D-03
 -.2512887756000D-01
  .9748899826000D-05
 -.1202192137000D-06
  .4128353939000D-04
 -.7215842918000D-06
  .5081738255000D+03
 -.9198903192000D+05
 -.2732264677000D+01
  .7499024351000D+05
  .1114060908000D-02
  .1083955159000D+01
 -.4490960312000D-04
 -.1380337847000D+01
 -.2371902232000D-07
  .3761652197000D-04
 -.2375166954000D-09
 -.1237640790000D-07
  .6766926453000D-06
```

```
 .4436658614060D+00
 .6172912655850D+00
-.1714092038860D+01
 .2664891756670D+01
-.2006798722650D+01
 .5054513976350D+00
-.1255990487150D+01
 .1374552965910D-02
-.6643534109710D-01
 .1277137136070D+01
-.8438642963590D+01
 .3101115288610D+01
-.5753632727380D+00
0.
0.
0.
0.
0.
0.
0.
-.1804475050700D+07 0.                    0.
 .7742666639300D+05 0.                    0.
-.1324165875400D+04 0.                    0.
 .1543814959500D+02 0.                    0.
-.5147900525700D-01 0.                    0.
 .1080917219600D-03 0.                    0.
-.5550178343700D-07 0.                    0.
-.6749005617100D+01 0.                    0.
 .3000000000000D+04 0.                    0.
 .4869146318103D+05 0.                    0.
-.4861658943347D+03 0.                    0.
 .4779399530000D+01 0.                     .1346953698000D+01
 .1757393941000D+01 0.                    -.3254677753000D+00
-.5665073910000D+00 0.                    0.
0.                  0.                    0.
 .1326326855000D+01 0.                    0.
 .1500000000000D+01 0.                    0.
 .9068000000000D+02 0.                    0.
 .1905550000000D+03 0.                    0.
 .1174300000000D-01 0.                    0.
-.1620427429000D+02  .2325800819000D-02
 .4270589027000D+03 -.2477927999000D+00
 .1402596278000D+02  .3880593713000D+02
-.3916837745000D+04 -.1579519146000D-06
-.3477099090000D-01  .3717991328000D-02
 .2136542674000D+02 -.9616989434000D+00
 .1436802482000D+04 -.3017352774000D-01
0.                   .4298153386000D+00
 .1696985927100D+00 0.
-.1333723450800D-01 0.
 .1400000000000D+01 0.
 .1680000000000D+03 0.
 .2814700000000D+02  .1567900000000D-01
0.                  0.                    0.
.00831434-.97066175E-02  600.00   90.68  200.00 10.1500  4.5980
 .6570101800000D-02 -.1909269420000D+03
 .6383501300000D-05  .4565597600000D-01
-.1871872800000D-06  .1850000000000D+01
-.5313482000000D-04 0.
-.9471173500000D-06 0.
0.                  0.
.287000E+00 .119000E+01 .355000E+00 .435200E+01 .138054E-22 .217000E+01
.164000E+00 .651271E-09 .374237E+02 .316714E+01 .780350E+00 .601030E+00
.160420E+02 .168000E+03 .368000E+01 .520000E+00
```

C2H4.COF

```
  0.          0.          0.          0.          0.          0.          0.
   .280540E+020.          0.          0.          0.           .167108E+010.
   -.2146684366683D-02
    .1791433722534D+00
   -.3675315603930D+01
    .3707178934669D+03
   -.3198282566709D+05
    .5809379774732D-04
   -.7895570824899D-01
    .1148620375835D+02
    .2713774629193D+05
   -.8647124319107D-05
    .1617727266385D-01
   -.2731527496271D+01
   -.2672283641459D-03
   -.4752381331990D-02
   -.6255637346217D+01
    .4576234964434D-03
   -.7534839269320D-05
    .1638171982209D-01
   -.3563090740740D-03
   -.1833000783170D+05
   -.1805074209985D+07
   -.4794587918874D+03
    .3531948274957D+07
   -.2562571039155D+01
    .1044308253292D+03
   -.1695303363659D-01
   -.1710334224958D+03
   -.2054114462372D-04
    .6727558766661D-02
   -.1557168403328D-06
   -.1229814736077D-04
    .4234325938573D-04
   -.6096215155940D+02
    .2031853127020D-01
   -.9254412658130D+00
    .2436307958880D+02
   -.8547456228880D+03
    .1239278681830D+04
   -.1427107117890D+04
    .8373586704050D+03
    .4322036965520D+03
   -.1379175411610D+04
    .1268586001240D+04
   -.5715523217130D+03
    .1060122343600D+03
   -.4790470601830D+01
    .1513813452830D-01
   -.4034560794450D+00
    .5086839202250D+01
   -.2467119979870D+02
    .9800309152470D+01
   -.2168465161220D+01
    .5603615762000D+06 0.          0.
   -.2141069802000D+05 0.          0.
    .2532008897000D+03 0.          0.
    .3554495281000D+01 0.          0.
   -.9951927478000D-02 0.          0.
    .5108931070000D-04 0.          0.
   -.1928667482000D-07 0.          0.
   -.2061703241000D+02 0.          0.
    .3000000000000D+04 0.          0.
   -.1054840584320D+05 0.          0.
    .6447430891887D+02 0.          0.
```

```
 .8209579800000D+01  0.                    0.
 .4315424145000D+01  0.                    0.
-.1692585975000D+01  0.                    0.
-.1976495575000D+00  0.                    0.
 .3446501098000D+01  0.                    0.
 .1500000000000D+01  0.                    0.
 .1039860000000D+03  0.                    0.
 .2823428000000D+03  0.                    0.
 .1212951400000D-03  0.                    0.
0.                   0.
0.                   0.
0.                   0.
0.                   0.
0.                   0.
0.                   0.
0.                   0.
0.                   0.
0.                   0.
0.                   0.
0.                   0.
0.                   0.
 .2334296694034D+02   .1425455127094D-03
0.                   0.                    0.
.00831434-.17200000E-01   400.00   103.99    40.00   7.6500   5.0404
0.                  -.3579238750000D+03
0.                   .2453321430000D-01
0.                   .2064500000000D+01
0.                   0.
0.                   0.
0.                   0.
```

C2H6.COF

```
0.          0.          0.          0.          0.          0.          0.
0.          0.          0.          0.          0.          0.          0.
 -.3204748852000D-03
  .6529792241000D-01
 -.1669704591000D+01
  .1147983381000D+03
 -.1854721998000D+05
  .4994149431000D-04
 -.4858871291000D-01
  .1225345776000D+02
  .8622615988000D+04
 -.1081290283000D-05
  .6279096996000D-02
 -.1716912675000D+01
 -.1640779401000D-04
 -.4356516111000D-02
 -.1966649699000D+01
  .4026724698000D-03
 -.6498241861000D-05
  .5111594139000D-02
 -.1113010349000D-03
 -.7157747547000D+03
 -.1848571024000D+07
 -.2137365569000D+03
  .6275079986000D+07
 -.9974911056000D+00
  .1129115014000D+03
 -.1026469558000D-01
 -.5660525915000D+03
 -.4209846430000D-04
  .2374523553000D-01
 -.1289637823000D-06
 -.5423801068000D-04
  .2239717230000D-02
  .3557074081980D+00
```

```
 .1099839659870D+00
 .1371418636620D+00
-.9801225235070D+00
 .1338489436060D+01
-.8076017312800D+00
-.1884527431980D+01
 .4486631930080D-02
-.1248903769190D+00
 .1797380770930D+01
-.1375304922580D+02
 .6941377045750D+01
-.1932968312710D+01
0.
0.
0.
0.
0.
0.
0.
-.6934140690900D+06 0.                    0.
 .3153483413500D+05 0.                    0.
-.6103375287000D+03 0.                    0.
 .9950792245900D+01 0.                    0.
-.2865787794800D-01 0.                    0.
 .9092289782100D-04 0.                    0.
-.5275010991500D-07 0.                    0.
-.1424359341100D+02 0.                    0.
 .3000000000000D+04 0.                    0.
 .2176008367499D+05 0.                    0.
-.2165173422429D+03 0.                    0.
 .8900377023000D+01 0.                    0.
 .1155950893100D+02 0.                    0.
-.4009244950000D+01 0.                    0.
-.1175263997000D+01 0.                    0.
 .7918066027000D+01 0.                    0.
 .1600000000000D+01 0.                    0.
 .9034800000000D+02 0.                    0.
 .3053300000000D+03 0.                    0.
 .1130842618000D-05 0.                    0.
0.                  0.
0.                  0.
0.                  0.
0.                  0.
0.                  0.
0.                  0.
0.                  0.
0.                  0.
 .2102436247000D+01 0.
-.1065920192000D+01 0.
 .1400000000000D+01 0.
 .3053300000000D+03 0.
 .2168000000000D+02  .1515400000000D-05
0.                  0.                    0.
.00831434-.21157025E-01   600.00    90.35    70.00   6.8750   4.8714
 .1114210000000D-01 -.2559650000000D+03
 .2066220000000D-04  .1400342000000D-01
-.1359820000000D-05  .2179000000000D+01
 .6304320000000D-04 0.
-.1456830000000D-06 0.
0.                  0.
.287000E+00 .119000E+01 .355000E+00 .435200E+01 .138054E-22 .232000E+01
.168000E+00 .742399E-090.           0.          0.          0.
.300701E+02 .240000E+03 .440110E+01 .350000E+00
```

C3H8.COF

```
   0.          0.          0.          0.          0.          0.          0.
   0.          0.          0.          0.          0.          0.          0.
    -.2804337729000D-03
     .1180666107000D+00
    -.3756325860000D+01
     .5624374521000D+03
    -.9354759605000D+05
    -.4557405505000D-04
     .1530044332000D+00
    -.1078107476000D+03
     .2218072099000D+05
     .6629473971000D-05
    -.6199354447000D-02
     .6754207966000D+01
     .6472837570000D-03
    -.6804325262000D-01
    -.9726162355000D+01
     .5097956459000D-02
    -.1004655900000D-03
     .4363693352000D-01
    -.1249351947000D-02
     .2644755879000D+05
    -.7944237270000D+07
    -.7299920845000D+03
     .5381095003000D+08
     .3450217377000D+01
     .9936666689000D+03
    -.2166699036000D+00
    -.1612103424000D+05
    -.3633126990000D-03
     .1108612343000D+01
    -.1330932838000D-04
    -.3157701101000D-02
     .1423083811000D+00
     .2776096607720D+00
     .9963162115260D-01
    -.9351030114790D-01
    -.3931811933810D+00
     .7803933323340D+00
    -.5946726552360D+00
    -.1703537178580D+02
     .8507185809450D-01
    -.1698995082710D+01
     .1842068338990D+02
    -.8153344355910D+02
     .3306123402780D+02
    -.7376365110310D+01
    0.
    0.
    0.
    0.
    0.
    0.
    0.
     .3125245009900D+07 0.                    0.
    -.1141525363800D+06 0.                    0.
     .1497165072000D+04 0.                    0.
    -.5404120433800D+01 0.                    0.
     .3921545289700D-01 0.                    0.
    -.2173891392600D-04 0.                    0.
     .4827454130300D-08 0.                    0.
     .3190701634900D+01 0.                    0.
     .1500000000000D+04 0.                    0.
    -.5905992207939D+05 0.                    0.
     .4723601648251D+03 0.                    0.
```

```
 .1541015327200D+02 0.                    .1422605000000D+01
 .1187073361500D+02 0.                   -.1797490000000D+00
-.8749583550000D+00 0.                   0.
-.2448971934000D+01 0.                   0.
 .1140096225900D+02 0.                   0.
 .1200000000000D+01 0.                   0.
 .8547000000000D+02 0.                   0.
 .3698500000000D+03 0.                   0.
 .1689532516000D-09 0.                   0.
-.1411329489600D+02  .3113890422000D-02
 .9682294015300D+03 -.2257559730000D+00
 .1368654503200D+02  .5674370999000D+02
-.1251162837800D+05 -.7840963643000D-04
 .1689108640000D-01  .2291785465000D-01
 .4352710944400D+02 -.2527939890000D+01
 .7659454347200D+04 -.6265334654000D-01
0.                   .2518064809000D+01
0.                  0.
0.                  0.
 .1120000000000D+01 0.
 .3590000000000D+03 0.
 .1663600000000D+02  .2377500000000D-09
0.                  0.                   0.
.00831434-.40000000E-01  600.00   85.47  100.00  5.0000  4.2477
 .1556263100000D-01 -.7180000000000D+03
 .7716282000000D-04  .2385650000000D+01
-.6039908400000D-05  .1283000000000D+01
 .5107405100000D-03 0.
-.4514118100000D-06 0.
0.                  0.
0.          0.          0.          0.           .138054E-220.
0.          0.          0.          0.          0.          0.
 .440972E+02 .359000E+030.           .390000E+00
```

ISOB.COF

```
0.          0.          0.          0.          0.          0.          0.
0.          0.          0.          0.          0.          0.          0.
  .1307325972000D-02
  .3927802742000D-01
 -.3185427394000D+01
  .7608825192000D+03
 -.1753919859000D+06
 -.2090019755000D-03
  .8959557971000D+00
 -.6816710130000D+03
 -.1111271045000D+06
  .3248737572000D-04
 -.1046526456000D+00
  .6536598969000D+02
  .3726503734000D-02
  .8553649395000D+00
  .2109987236000D+03
 -.1401267363000D+00
  .5213089327000D-02
 -.1925026382000D+01
  .7640067895000D-01
  .3425854273000D+06
 -.3373475924000D+08
  .1180683444000D+05
  .1529683738000D+09
  .3323837416000D+03
  .6423169487000D+04
  .3891706042000D+01
 -.1494755736000D+06
 -.1720240173000D-02
  .2894195375000D+02
  .2005086329000D-03
```

```
-.4448393005000D-01
 .8028488415000D+01
 .3432512286730D+00
 .4828577762610D-01
 .5484324610530D+00
-.1884263998340D+01
 .2028124065780D+01
-.9734823703320D+00
-.9587205839600D+01
 .3912955870750D-01
-.8482763798650D+00
 .9883018121350D+01
-.4930250474110D+02
 .2097730743050D+02
-.4921886633430D+01
0.
0.
0.
0.
0.
0.
0.
 .1702791900600D+08 0.                    0.
-.4726972473700D+06 0.                    0.
 .4730140658100D+04 0.                    0.
-.1723172327800D+02 0.                    0.
 .5849134429100D-01 0.                    0.
 .8944035188600D-05 0.                    0.
-.1827459919700D-07 0.                    0.
-.1928302196200D+02 0.                    0.
 .3000000000000D+04 0.                    0.
-.1977633864428D+06 0.                    0.
 .1076385671262D+04 0.                    0.
 .1264889651000D+02 0.                     .1449797353000D+01
 .1074641516000D+02 0.                    -.1685643887000D+00
-.2191129109000D+01 0.                    0.
-.2155822575000D+01 0.                    0.
 .8832766439000D+01 0.                    0.
 .1400000000000D+01 0.                    0.
 .1135500000000D+03 0.                    0.
 .4078500000000D+03 0.                    0.
 .1948100000000D-07 0.                    0.
-.2055498053000D+02  .4307008989000D-02
 .1357076181000D+04 -.1509010974000D+01
 .1893774336000D+02  .4693712392000D+03
-.1822277344000D+05 -.3554280979000D-03
-.4599387773000D-02  .1841552874000D+00
 .6305247065000D+02 -.3892338766000D+02
 .1282253921000D+05 -.9354624917000D-01
0.                   .7114330590000D+01
 .1687838652000D+01 0.
0.                   0.
 .1400000000000D+01 0.
 .4078500000000D+03 0.
 .1275500000000D+02  .2063400000000D-07
0.                   0.                   0.
.00831434-.67115896E-01   600.00   113.55    35.00   3.8600   3.6400
 .1986702600000D-01 -.4300000000000D+02
 .1760005300000D-03  .1373820000000D-10
-.1526737200000D-04  .6080000000000D+01
 .9947290400000D-03 0.
-.5637502400000D-06 0.
0.                   0.
.287000E+00 .119000E+01 .355000E+00 .435200E+01 .138054E-22 .207000E+01
.140000E+00 .910218E-09 .347138E-02 .101207E+02 .466392E+00 .100344E+01
.581243E+02 .418000E+03 .509217E+01 .250000E+00
```

NORB. COF

```
 0.            0.            0.            0.            0.            0.            0.
 0.            0.            0.            0.            0.            0.            0.
   .1537401046030D-02
  -.1609800346110D-01
  -.9797824590100D+00
   .4996606745040D+02
  -.1021156076870D+06
   .2360321477560D-03
  -.1374757570930D+00
  -.9070387338650D+02
   .3854217482130D+05
  -.3494537107000D-05
   .1573611227140D-01
   .1023014740680D+02
   .1823357373310D-02
  -.4041143077870D+00
   .1879798557830D+00
   .3620887950400D-01
  -.7387622482660D-03
  -.2186185905630D+00
   .1188027290270D-01
   .7068541987130D+05
  -.2194698857960D+08
  -.1824543612680D+04
   .2067903772770D+09
   .1117575501450D+02
   .5587799259860D+04
  -.1595790540260D+01
  -.1480342146220D+06
  -.2452063282010D-01
   .2183052593090D+02
  -.9239906273380D-05
  -.2052677766390D+00
   .3876390448200D+01
   .4041621499070D+00
   .9607640867320D-01
   .3404715226650D+00
  -.1729592472230D+01
   .2214509591330D+01
  -.1195654636800D+01
  -.5007387533220D+01
   .9593278394870D-02
  -.2995224440540D+00
   .4457489568490D+01
  -.3041854550990D+02
   .1424771122650D+02
  -.3608627293560D+01
 0.
 0.
 0.
 0.
 0.
 0.
 0.
   .3880231019400D+06 0.                        0.
  -.1544429689000D+06 0.                        0.
   .2845508223900D+04 0.                        0.
  -.1349151137600D+02 0.                        0.
   .6614259535300D-01 0.                        0.
  -.2430796502800D-04 0.                        0.
   .1504424842900D-09 0.                        0.
  -.8393342346700D+01 0.                        0.
   .3000000000000D+04 0.                        0.
  -.1090160645491D+06 0.                        0.
   .8662371372633D+03 0.                        0.
```

```
-.7645674906000D+01  0.                    .1530992335000D+01
 .2457845942700D+02  0.                   -.2114511021000D+00
-.1096617182000D+01  0.                   0.
-.2890833730000D+00  0.                   0.
 .2516192927700D+02  0.                   0.
 .1030000000000D+01  0.                   0.
 .1348600000000D+03  0.                   0.
 .4251600000000D+03  0.                   0.
 .6735758052000D-06  0.                   0.
-.2724386845000D+02   .4024170074000D-02
 .8012766611000D+03   .1561435847000D+01
 .2503978646000D+02  -.6004381127000D+03
-.1309704275000D+05  -.7547260841000D-03
-.8313305258000D-01  -.2069676662000D-01
 .6636975027000D+02   .9382534978000D+02
 .9849317662000D+04  -.1711371457000D+00
0.                    .3647724935000D+02
 .1630521851000D+01  0.
0.                    0.
 .1400000000000D+01  0.
 .4251600000000D+03  0.
 .1265000000000D+02   .6007200000000D-06
0.                    0.                  0.
.00831434-.65077051E-01   500.00   134.86    70.00   3.9200   3.7960
 .2069763100000D-01  -.3634000000000D+03
 .6734573100000D-04   .7134170000000D-02
-.6611178500000D-05   .2210000000000D+01
-.1115193300000D-03  0.
-.1202982000000D-05  0.
0.                    0.
.287000E+00 .119000E+01 .355000E+00 .435200E+01 .138054E-22 .207000E+01
.140000E+00 .910218E-09 .769608E-03 .132533E+02 .485554E+00 .101021E+01
.581243E+02 .440000E+03 .503103E+01 .320000E+00
```

```
      PROGRAM HELIUM
      IMPLICIT REAL*8(A-H)
      IMPLICIT REAL*8(O-Z)
      IMPLICIT INTEGER*4(I-N)
      COMMON/LIM/TUL,TLL,PUL,TCC,DCC,PCC
1000  FORMAT(//'     THIS PROGRAM PROVIDES THE THERMODYNAMIC PROPERTIES
     1OF HELIUM',/,'                    FROM 2 TO 1500 K (-456 TO 2240 F)'
     A,/'                 WITH PRESSURES TO 100 MPA (14503 PSIA)'/)
      WRITE(*,1000)
      CALL INFO
      IP=3
      CALL FDATA
      TTP=TLL
      PTP=.005D0
      EM=4.0026
1010  FORMAT(I1)
    1 CONTINUE
  120 WRITE(*,1040)
1040  FORMAT(' FOR ENGINEERING UNITS ENTER "0", FOR METRIC ENTER "1"',/)
      READ(*,1010)IU
      WRITE(*,1050)
1050  FORMAT(' FOR SATURATION PROPERTIES ENTER "0", FOR FLUID ENTER '
     A '"1"',/)
      READ(*,1010)IC
      WRITE(*,1060)
1060  FORMAT(' FOR A SINGLE POINT ENTER "0", FOR A TABLE ENTER "1"',/)
      READ(*,1010)IV
  160 IF(IC.EQ.0)GO TO 240
      IF(IV.EQ.1)GO TO 330
  170 IF(IU.EQ.0)GO TO 180
      WRITE(*,1080)
      READ(*,*)PI,D,T
      GO TO 190
  180 WRITE(*,1070)
1070  FORMAT(' ENTER PRESSURE(PSIA), DENSITY(LB/CU FT), AND TEMPERATURE'
     A '(F)',/)
      READ(*,*)P,D,T
      PI=(P/14.695949D0)*.101325
      D=D*16.01846371D0/EM
      T=(T-32.D0)/1.8D0+273.15D0
  190 IF(PI.LE.0.0D0.AND.D.LE.0.0D0)GO TO 110
      IF(PI.GT.0.0D0.AND.D.GT.0.0D0)GO TO 200
      IF(PI.LE.0.0D0.AND.T.NE.0.0D0)GO TO 220
      IF(PI.NE.0.0D0.AND.T.NE.0.0D0)GO TO 210
      GO TO 1
1080  FORMAT(' ENTER PRESSURE(MPA), DENSITY(MOL/L), AND TEMPERATURE(K)'
     A /)
  200 P=PI/.101325
      T=FIND T(P,D)
      CALL LIMITS(PI,T,IL)
      IF(IL.LE.0)GO TO 170
      GO TO 230
  210 P=PI/.101325
      CALL LIMITS(PI,T,IL)
      IF(IL.LE.0)GO TO 170
      D=FIND D(P,T)
```

```
      GO TO 230
  220 P=FIND P(D,T)
      PI=P*.101325
      CALL LIMITS(PI,T,IL)
      IF(IL.LE.0)GO TO 170
  230 CALL REPRO(PI,D,T,IU,IV,IC,IP,TF,TDEL)
      GO TO 170
  240 WRITE(*,1090)
 1090 FORMAT(' FOR SATURATED LIQUID ENTER "0", FOR VAPOR ENTER "1"',/)
      READ(*,1010)IP
      IF(IV.EQ.1)GO TO 330
      WRITE(*,1095)
 1095 FORMAT(' TO ENTER WITH TEMPERATURE ENTER "0", FOR PRESSURE "1"',/)
      READ(*,1010)II
      IF(II.EQ.1)GO TO 290
  250 IF(IU.EQ.1)GO TO 260
 1100 FORMAT(' ENTER A TEMPERATURE IN DEGREES F, ENTER 0 FOR RESTART',/)
      WRITE(*,1100)
      READ(*,*)TI
      IF(TI.EQ.0.0D0)GO TO 110
      T=(TI-32.D0)/1.8D0+273.15D0
      GO TO 270
  260 WRITE(*,1110)
 1110 FORMAT(' ENTER A TEMPERATURE(K) ,ENTER 0 FOR RESTART',/)
      READ(*,*)T
  270 IF(T.LT..000001D0)GO TO 110
      IF(T.GT.TCC.OR.T.LT.TTP)GO TO 280
      P=VPN(T)
      IF(IP.EQ.0)P=P+.00001D0
      IF(IP.EQ.1)P=P-.00001D0
      D=FIND D(P,T)
      PI=P*.101325
      CALL RE PRO(PI,D,T,IU,IV,IC,IP,TF,TDEL)
      GO TO 250
  280 X1=(TTP-273.15D0)*1.8D0+32.D0
      X2=(TCC-273.15D0)*1.8D0+32.D0
      WRITE(*,1120)TTP,TCC,X1,X2
 1120 FORMAT(' FOR SATURATION ',F6.2,' < TEMP < ',F6.2,' K',/,
     A ' OR ',F7.2,' < TEMP < ',F7.2,' F',/)
      GO TO 250
  290 IF(IU.EQ.1)GO TO 300
      WRITE(*,1130)
 1130 FORMAT(' ENTER A PRESSURE IN LB/SQ IN   0 RESTRATS PROGRAM',/)
      READ(*,*)P
      PI=(P/14.695949D0)*.101325D0
      P=PI/.101325D0
      IF(PI.LE.0.0D0)GO TO 110
      GO TO 310
  300 WRITE(*,1140)
 1140 FORMAT(' ENTER A PRESSURE(MPA)  0 RESTARTS PROGRAM',/)
      READ(*,*)PI
      IF(PI.LE.0.0D0)GO TO 110
      P=PI/.101325
  310 IF(PI.GT.PCC.OR.PI.LT.PTP)GO TO 320
      T=FIND TV(P)
      P=VPN(T)
      IF(IP.EQ.1)P=P-.00001D0
      IF(IP.EQ.0)P=P+.00001D0
      D=FIND D(P,T)
      PI=P*.101325
      CALL RE PRO(PI,D,T,IU,IV,IC,IP,TF,TDEL)
      GO TO 290
```

```
 320 PTPF=PTP*14.695949/.101325
     PCCF=PCC*14.695949/.101325
     WRITE(*,1150) PTP,PCC,PTPF,PCCF
1150 FORMAT(' YOUR INPUT PRESSURE IS OUTSIDE THE RANGE OF SATURATION'
    A ' PRESSURES'/' FOR THIS FLUID THE RANGE IS ',F6.5,' TO ',F6.3,
    B' MPA,'/' OR ',F6.5,' TO ',F6.3,' PSIA'/'  TRY AGAIN',/)
     GO TO 290
 330 IF(IC.EQ.1)GO TO 370
     IF(IU.EQ.1)GO TO 340
     WRITE(*,1160)
1160 FORMAT('  ENTER A STARTING TEMPERATURE, A FINAL TEMPERATURE'
    A /' AND A TEMPERATURE INCREMENT, IN DEGREES F AND IN THAT ORDER'/
    B '  ENTER 0,0,0 TO RESTART'/)
     READ(*,*)TS,TF,TDEL
     IF(TDEL.LE.0.0D0)GO TO 110
     TS=(TS-32.D0)/1.8D0+273.15D0
     TF=(TF-32.D0)/1.8D0+273.15D0
     TDEL=TDEL/1.8D0
     IF(TS.LT.TTP.OR.TS.GT.TCC)GO TO 360
     IF(TF.LT.TTP.OR.TF.GT.TCC)GO TO 360
     GO TO 350
 340 WRITE(*,1170)
1170 FORMAT(' ENTER A STARTING TEMPERATURE, A FINAL TEMPERATURE'
    1/' AND A TEMPERATURE INCREMENT IN KELVINS AND IN THAT ORDER',/
    2'  ENTER 0,0,0 TO RESTART PROGRAM'/)
     READ(*,*)TS,TF,TDEL
     IF(TDEL.LE.0.0D0)GO TO 110
     IF(TS.LT.TTP.OR.TS.GT.TCC)GO TO 360
     IF(TF.LT.TTP.OR.TF.GT.TCC)GO TO 360
 350 T=TS
     P=VPN(T)
     IF(IP.EQ.0)P=P+.00001D0
     IF(IP.EQ.1)P=P-.00001D0
     D=FIND D(P,T)
     PI=P*.101325
     CALL RE PRO(PI,D,T,IU,IV,IC,IP,TF,TDEL)
     GO TO 330
 360 X1=(TTP-273.15D0)*1.8D0+32.D0
     X2=(TCC-273.15D0)*1.8D0+32.D0
     WRITE(*,1180)TTP,TCC,X1,X2
1180 FORMAT(' FOR SATURATION,  ',F6.2,' < TEMP < ',F6.2,' K',/,
    A ,13X,'OR, ',F7.1,' < TEMP < ',F7.1,' F.  TRY AGAIN.',/)
     GO TO 330
 370 IF(IU.EQ.1)GO TO 380
     WRITE(*,1190)
1190 FORMAT(' ENTER PRESSURE(PSIA), STARTING TEMPERATURE(F), FINAL '
    A 'TEMPERATURE(F)'/' AND A TEMPERATURE INCREMENT, IN THAT ORDER',/
    B '  ENTER 0,0,0,0 TO RESTART PROGRAM'/)
     READ(*,*)P,TS,TF,TDEL
     IF(TDEL.LE.0.0D0)GO TO 110
     PI=(P/14.695949D0)*.101325D0
     T=(TS-32.D0)/1.8D0+273.15D0
     TF=(TF-32.D0)/1.8D0+273.15D0
     TDEL=TDEL/1.8D0
     P=PI/.101325
     CALL LIMITS(PI,T,IL)
     IF(IL.LE.0)GO TO 370
     CALL LIMITS(PI,TF,IL)
     IF(IL.LE.0)GO TO 370
     GO TO 390
 380 WRITE(*,1200)
1200 FORMAT(' ENTER A PRESSURE(MPA), A STARTING TEMPERATURE(K), A '
```

```
     1'FINAL TEMPERATURE AND A'/' TEMPERATURE INCREMENT'
     2' AND IN THAT ORDER, TO RESTART PROGRAM ENTER "0,0,0,0"',/)
      READ(*,*)PI,TS,TF,TDEL
      IF(TDEL.LE.0.0D0)GO TO 110
      T=TS
      P=PI/.101325
      CALL LIMITS(PI,T,IL)
      IF(IL.LE.0)GO TO 370
      CALL LIMITS(PI,TF,IL)
      IF(IL.LE.0)GO TO 370
  390 D=FIND D(P,T)
      CALL RE PRO(PI,D,T,IU,IV,IC,IP,TF,TDEL)
      GO TO 370
  110 CONTINUE
      WRITE(*,1210)
 1210 FORMAT(//' FOR MORE PROPERTIES ENTER 0, TO TERMINATE ENTER 1')
      READ(*,1010)IM
      IF(IM.EQ.0)GO TO 1
  999 CONTINUE
      STOP
      END
      SUBROUTINE REPRO(PI,D,T,IU,IV,IC,IP,TF,TDEL)
      IMPLICIT REAL*8(A-H)
      IMPLICIT REAL*8(O-Z)
      IMPLICIT INTEGER*4(I-N)
      N=500
      EM=4.0026
      P=PI/.101325
      IF(IV.EQ.0)TF=T-1.D0
      IF(IU.EQ.0)GO TO 100
      WRITE(*,1000)
      WRITE(*,1010)
      WRITE(*,1020)
      GO TO 110
  100 WRITE(*,1000)
      WRITE(*,1030)
      WRITE(*,1040)
  110 CONTINUE
      DO 210 I=1,N
      IF(I.EQ.1)GO TO 120
      D=FIND D(P,T)
  120 H=ENTHAL(P,D,T)
      E=H-101.325D0*P/D
      S=ENTROP(D,T)
      W=SOUND(D,T)
      CPP=CP(D,T)
      CVV=CV(D,T)
  150 V=VISC(D,T)
      TH=THERM(D,T)*100.D0
      EPS=FDIEL(D)
      IF(IU.EQ.0)GO TO 160
      PO=P*.101325
      WRITE(*,2030) PO,T,D,E,H,S,CVV,CPP,W,V,TH,EPS
      GO TO 200
  160 H=H/(2.324445D0*EM)
      E=E/(2.324445D0*EM)
      S=S/(4.184001D0*EM)
      CPP=CPP/(4.184001D0*EM)
      CVV=CVV/(4.184001D0*EM)
      W=W*3.280840D0
      PO=P*14.695949D0
      DO=D*EM/16.01846371D0
```

```
      TO=T*1.8D0-459.67D0
  190 V=VISC(D,T)*.0067196897D0
      TH=THERM(D,T)*.000578176D0
      EPS=FDIEL(P,D,T)
      WRITE(*,3030) PO,TO,DO,E,H,S,CVV,CPP,W,V,TH,EPS
  200 T=T+TDEL
      IF(T.GT.TF+.01D0)GO TO 220
      IF(IC.NE.0)GO TO 210
      P=VPN(T)
      IF(IP.EQ.0)P=P+.00001D0
      IF(IP.EQ.1)P=P-.00001D0
  210 CONTINUE
  220 CONTINUE
      WRITE(*,1000)
 1000 FORMAT(' ')
      RETURN
 1010 FORMAT(3X,'P',5X,'T',6X,'DEN',5X,'E',6X,'H',6X,'S',4X,'CV',4X,
     A 'CP',3X,'SOUND',2X,'VISC',2X,'COND',2X,'DIEL')
 1020 FORMAT(3X,'MPA',3X,'K',6X,'MOL/L',2X,'=== J/MOL ==',2X,'==== ',
     A 'J/MOL-K ===',2X,'M/S',3X,'PA-S',1X,'MW/M-K',2X,'==',/,61X,'E+6')
 1030 FORMAT(3X,'P',5X,'T',7X,'DENS',3X,'E',8X,'H',5X,'S',5X,'CV',
     A 4X,'CP',2X,'SOUND',1X,'VISC',2X,'COND',2X,'DIEL')
 1040 FORMAT(3X,'PSIA',2X,'F',7X,'LB/',3X,'==== BTU/ ===',1X,'======',
     A ' BTU/ =====',2X,'F/S',3X,'LB/',2X,'BTU/',2X,'==',/,17X,'CU FT',
     B 6X,'LB',14X,'LB-F',13X,'FT-S',1X,'FT-HR-F',/,62X,'E+5')
 2030 FORMAT(F8.3,F7.2,F7.3,2F7.0,F6.1,F5.1,F6.1,F6.0,F6.1,F6.1,F8.5)
 3030 FORMAT(F8.1,F7.2,F7.3,2F7.1,3F6.3,F6.0,F5.2,F6.4,F8.5)
      END
      SUBROUTINE INFO
      WRITE(*,101)
  101 FORMAT('                              WRITTEN BY'//
     A'                        ROBERT D. MCCARTY'/
     1'                      THERMOPHYSICS DIVISION'/
     2'                  CENTER FOR CHEMICAL ENGINEERING'/
     3'                    NATIONAL BUREAU OF STANDARDS'/
     4'                         BOULDER, COLORADO'//
     5'                           DISTRIBUTED BY'//
     A'               THE OFFICE OF STANDARD REFERENCE DATA'/
     6'             NATIONAL BUREAU OF STANDARDS, WASHINGTON, DC'/)
      WRITE(*,100)
  100 FORMAT(/ ' WHEN THE PROGRAM ASKS FOR A PRESSURE, DENSITY AND'
     *' TEMPERATURE,'/ ' ENTER ANY TWO AND A ZERO FOR THE THIRD.'/
     * ' TO TERMINATE THE PROGRAM ENTER ZERO FOR ALL THREE.'/)
      RETURN
      END
```

```
      SUBROUTINE FDATA(IF)
      IMPLICIT REAL*8(A-H)
      IMPLICIT REAL*8(O-Z)
      IMPLICIT INTEGER*4(I-N)
      DIMENSION B(27,3)
      COMMON/COEF/B
      COMMON/LIM/TUL,TLL,PUL,TCC,DCC,PCC
      OPEN(5,FILE='HELIUM.COF')
      DO 60 J=1,3
      DO 60 I=1,27
   60 READ(5,101)B(I,J)
  101 FORMAT(D20.13)
      READ(5,102)TUL,TLL,PUL,TCC,DCC,PCC
      CLOSE(5,STATUS='KEEP')
  102 FORMAT(F10.8,E14.8,3F8.2,2F8.4)
      RETURN
      END
      SUBROUTINE LIMITS(PI,T,IL)
      IMPLICIT REAL*8(A-H)
      IMPLICIT REAL*8(O-Z)
      IMPLICIT INTEGER*4(I-N)
      COMMON/LIM/TUL,TLL,PUL,TCC,DCC,PCC
      P=PI/.101325
      IF(PI.GT. PUL)GO TO 10
      IF(T .GT. TUL.OR.T .LT. TLL)GO TO 12
      PM=PMELT(T)
      IF(P .GT. PM) GO TO 20
      IL=1
      RETURN
   10 PULF=PUL*14.6959496/.101325
      WRITE(*,11)PUL,PULF
   11 FORMAT(' THE INPUT PRESSURE IS OUT OF THE RANGE OF THIS EQUATION '
     1/' THE RANGE FOR THIS EQUATION IS FROM 0 TO ',F6.0,' MPA'
     2/'                                     OR ',F7.0,' PSIA')
      IL=0
      RETURN
   12 TLLF= (TLL-273.15D0)*1.8D0+32.D0
      TULF= (TUL-273.15D0)*1.8D0+32.D0
      WRITE(*,13) TLL,TUL,TLLF,TULF
   13 FORMAT(' THE INPUT TEMPERATURE IS OUT OF RANGE'
     A /' THE RANGE FOR THIS EQUATION IS  ',F6.2,' K   TO ',F6.0,' K',/,
     B 27X,' OR ',F8.2,' F   TO ',F6.0,' F')
      IL=0
      RETURN
   20 TM=TMELT(P)
      TF=(TM-273.15D0)*1.8D0+32.D0
      WRITE(*,22) TM,TF
   22 FORMAT(' SOLID PHASE DETECTED.',/,' FOR THIS PRESSURE,  TEMP'
     A ' SHOULD EXCEED ',F8.3,' K, OR',F9.3,' F')
      IL=0
      END
      DOUBLE PRECISION FUNCTION CV(D,T)
      IMPLICIT REAL*8(A-H)
      IMPLICIT REAL*8(O-Z)
      IMPLICIT INTEGER*4(I-N)
C  CALCULATES CV(J/(MOL*K)).  INPUT DENS(MOL/L) AND TEMP(K).
      CALL PROPS(PP,D,T,6)
      CV=PP
      END
      DOUBLE PRECISION FUNCTION ENTHAL(P,D,T)
      IMPLICIT REAL*8(A-H)
      IMPLICIT REAL*8(O-Z)
      IMPLICIT INTEGER*4(I-N)
```

```
      DD=D
      TT=T
      CALL PROPS(UD,DD,TT,5)
      ENTHAL=(UD)
      END
      DOUBLE PRECISION FUNCTION ENTROP(D,T)
      IMPLICIT REAL*8(A-H)
      IMPLICIT REAL*8(O-Z)
      IMPLICIT INTEGER*4(I-N)
C  CALCULATES ENTROPY(J/(MOL-K), FROM INPUT OF DENSITY(MOL/L) AND TEMP(K).
      DD=D
      TT=T
      CALL PROPS(SD,DD,TT,4)
      ENTROP=(SD)
      END
      DOUBLE PRECISION FUNCTION FINDP(D,T)
      IMPLICIT REAL*8(A-H)
      IMPLICIT REAL*8(O-Z)
      IMPLICIT INTEGER*4(I-N)
      DIMENSION G(32),VP(9)
      COMMON/DATA/G,R,GAMMA,VP,DTP,PCC,PTP,TCC,TTP,TUL,TLL,PUL,DCC
      DD=D
      TT=T
      IF(TT.LT.TCC)GO TO 10
    1 CALL PROPS(PP,DD,TT,1)
      FINDP=PP
      RETURN
   10 P=VPN(TT)
      DV=FINDD(P-.0001D0,TT)
      DL=FINDD(P+.0001D0,TT)
      IF(DD.LE.DV.OR.DD.GE.DL)GO TO 1
      WRITE(*,100)DV,DL,DD
      CALL PROPS(PP,DV,TT,1)
      FINDP=PP
      D=DV
  100 FORMAT(' THE STATE POINT YOU HAVE SPECIFIED CORRESPONDS TO A '
     1/' DENSITY IN THE LIQUID VAPOR COEXISTENCE REGION'
     2/' THE DENSITY OF THE SATURATED VAPOR IS ',F6.4,' MOLES/LITER'
     3/' THE DENSITY OF THE SATURATED LIQUID IS ',F8.4,' MOLES/LITER'
     4/' AND THE INPUT DENSITY IS ',F8.4,' MOLES/LITER'
     5/' SATURATED VAPOR IS ASSUMED')
      END
      DOUBLE PRECISION FUNCTION FINDT(P,D)
      IMPLICIT REAL*8(A-H)
      IMPLICIT REAL*8(O-Z)
      IMPLICIT INTEGER*4(I-N)
C  RETURNS TEMPERATURE(K), FROM THE 32-TERM MBWR EQN OF STATE.
C  INPUT IS PRESSURE(MPA) AND DENSITY(MOL/L).
      DIMENSION G(32),VP(9)
      COMMON/DATA/G,R,GAMMA,VP,DTP,PCC,PTP,TCC,TTP,TUL,TLL,PUL,DCC
      PP=P
      DD=D
      IF(P.GE.PCC)GO TO 1
      TSAT=FINDTV(PP)
      DV=FINDD(PP-.00001D0,TSAT)
      DL=FINDD(PP+.0001D0,TSAT)
      IF(DD.GT.DV.AND.DD.LT.DL)GO TO 30
      TT=TSAT
      GO TO 2
    1 TT=TCC
    2 DO 10 I=1,10
      CALL PROPS(P2,DD,TT,1)
      IF(DABS(PP-P2)-1.D-7*PP)20,20,11
   11 CALL PROPS(DP,DD,TT,3)
      CORR=(P2-PP)/DP
      IF(DABS(CORR)-1.D-5)20,20,10
   10 TT=TT-CORR
   20 FINDT=TT
```

```
      RETURN
   30 FINDT=TSAT
      D=DV
      WRITE(*,100)DV,DL,DD
  100 FORMAT(' THE STATE POINT YOU HAVE SPECIFIED CORRESPONDS TO'
     1/' A DENSITY IN THE LIQUID VAPOR COEXISTENCE REGION'
     2/' DENSITY OF THE SATURATED VAPOR IS',F8.4,' MOLES/LITER'
     3/' DENSITY OF THE SATURATED LIQUID IS',F8.4,' MOLES/LITER'
     4/' INPUT DENSITY IS',F8.4,' MOLES/LITER'
     5/' SATURATED VAPOR CONDITIONS ARE ASSUMED')
      END
       DOUBLE PRECISION FUNCTION FIND D(PI,TI)
      IMPLICIT REAL*8 (A-H)
      IMPLICIT REAL*8 (O-Z)
      IMPLICIT INTEGER*4(I-N)
      T=TI
      P=PI
      IF(T.LT.5.2D0)GO TO 6
      PM=1001.D0
      PM=1.0D+5
      IF(T.LT.15.D0)PM=PMELT(T)
      IF(PM.LT.P)GO TO 30
      IF(T.GT.100.D0)GO TO 1
      PC=2.2449D0+(T-5.2014D0)*1.76D0
      IF(P.LT.PC)GO TO 1
      PM=200.D0+(T-5.2D0)*12.31D0
      D=17.399D0+((PM-PC)/(PM-PC+1.D0))*2.33D0*17.399D0
      GO TO 7
    2 D=.0001D0
      IF(T.LT.4.2D0)GO TO 7
    1 VB=VIRB(T)
      RT=0.0820558D0*T
      P1=RT/P
      D=1./(P1+VB)
      GO TO 7
    6 IF(P.LT.VPN(T))GO TO 2
      DS=46.18D0+(T-2.D0)*4.02D0
      DL=SATL(T)*1000.D0/4.0026D0
      DEL=DS-DL
      PM=PMELT(T)
      IF(P.GT.PM)GO TO 30
      D=DL+DEL*P/PM
    7 DO 10 I=1,50
      CALL PROPS(P2,D,T,1)
      IF(DABS(P-P2)-1.D-7*P)20,20,8
    8 CALL PROPS(DP,D,T,2)
      CORR=(P2-P)/DP
      IF(DABS(CORR)-1.D-7*D)20,20,10
   10 D=D-CORR
      FIND D=0.D0
      RETURN
   20 FIND D=D
      RETURN
   30 FIND D=0.D0
      RETURN
      END
      SUBROUTINE PROPS(PP,DD,TT,ICON)
      IMPLICIT REAL*8 (A-H)
      IMPLICIT REAL*8 (O-Z)
      IMPLICIT INTEGER*4(I-N)
      DIMENSION A(26),B(27,3)
      COMMON/COEF/B
      GO TO(1000,3000,2000,4000,5000,6000)ICON
 1000 KP=1
      GO TO 10
C     ENTRY DPDT
 2000 KP=2
      GO TO 10
```

```
C     ENTRY DPDD
 3000 KP=3
      GO TO 10
C     ENTRY ENTROP
 4000 KP=4
      GO TO 10
C     ENTRY ENTHAL
 5000 KP=5
      GO TO 10
C     ENTRY CV
 6000 KP=6
   10 K1=0
      KH=1
      K=1
      KK=1
      K4=1
      IF(ID.NE.0)GO TO 20
      IF(TT.GE.15.D0)GO TO 20
      IF(TT.GT.10.D0)GO TO 30
      IF(DD.GT.17.3987D0)GO TO 40
   11 I=1
      T=TT
      D=DD
    8 GO TO (9,100,200,300,400,500)KP
    9 D2=D*D
      D3=D2*D
      D4=D3*D
      D5=D4*D
      GAMMA=B(27,I)
      EX=DEXP(D2*GAMMA)
      EXD3=EX*D3
      EXD5=EX*D5
      M=I
      N=1
      A(N)=D5*D
      N=N+1
      A(N)=A(N-1)/T
      N=N+1
      DO 2 I=1,6
      FI=I
      A(N)=D5*T**(.75D0-FI/4.D0)
    2 N=N+1
      DO 3 I=1,4
      FI=I
      A(N)=D4*T**(1.5D0-FI)
    3 N=N+1
      DO 1 I=1,8
      FI=I
      A(N)=D3*T**(1.5D0-FI/2.D0)
      N=N+1
    1 CONTINUE
      DO 4 I=1,3
      FI=I
      A(N)=EXD3*T**(1.D0-FI)
    4 N=N+1
      DO 5 I=1,3
      FI=I
      A(N)=EXD5*T**(1.D0-FI)
    5 N=N+1
      N=N-1
      I=M
    7 P=0.D0
      DO 15 J=1,N
   15 P=P+B(J,I)*A(J)
      P=P+.0820558D0*D*T*(1.+VIRB(T)*D)
      IF(KH.LT.1)GO TO 413
      GO TO(50,50,30,40)K
  100 D2=D*D
```

```
      D3=D**3
      D4=D3*D
      D5=D4*D
      D6=D5*D
      T2=T*T
      T3=T2*T
      T4=T**4
      M=I
      GAMMA=B(27,M)
      EX=DEXP(D2*GAMMA)
      N=1
      R=.0820558D0
      A(N)=0.0D0
      N=N+1
      A(N)=(-1.D0)*D6/T2
      N=N+1
      DO 102 I=1,6
      FI=I
      A(N)=D5*T**(.75D0-FI/4.D0-1.D0)*(.75D0-FI/4.D0)
102   N=N+1
      DO 103 I=1,4
      FI=I
      A(N)=D4*T**(1.5D0-FI/1.D0-1.D0)*(1.5D0-FI)
103   N=N+1
      DO 101 I=1,8
      FI=I
      A(N)=D3*T**(1.5D0-FI/2.D0-1.D0)*(1.5D0-FI/2.D0)
101   N=N+1
      DO 104 I=1,3
      FI=I
      A(N)=EX*D3*T**(1.D0-FI-1.D0)*(1.D0-FI)
104   N=N+1
      DO 105 I=1,3
      FI=I
      A(N)=EX*D5*T**(1.D0-FI-1.D0)*(1.D0-FI)
105   N=N+1
      N=N-1
      P=0
      DO 115 J=1,N
115   P=P+A(J)*B(J,M)
      P=P+R*D*(1.D0+VIRB(T)*D)+R*D*T*DBDT(T)*D
      I=M
      GO TO(50,50,30,40)K
200   D2=D*D
      D3=D2*D
      D4=D3*D
      D5=D4*D
      M=I
      GAMMA=B(27,M)
      EX=DEXP(D2*GAMMA)
      DEX=GAMMA*2.D0*D*EX
      N=1
      R=0.0820558D0
      A(N)=6.D0*D5
      N=N+1
      A(N)=A(N-1)/T
      N=N+1
      DO 202 I=1,6
      FI=I
      A(N)=5.D0*D4*T**(.75D0-FI/4.D0)
202   N=N+1
      DO 203 I=1,4
      FI=I
      A(N)=D3*4.D0*T**(1.5D0-FI)
203   N=N+1
      DO 201 I=1,8
      FI=I
      A(N)=D2*3.D0*T**(1.5D0-FI/2.D0)
```

```
201 N=N+1
    DO 204 I=1,3
    FI=I
    A(N)=(DEX*D3+3.D0*D2*EX)*T**(1.D0-FI)
204 N=N+1
    DO 205 I=1,3
    FI=I
    A(N)=(DEX*D5+5.D0*D4*EX)*T**(1.D0-FI)
205 N=N+1
    N=N-1
    P=0
    DO 215 J=1,N
215 P=P+A(J)*B(J,M)
    I=M
    P=P+R*T*(1.D0+2.D0*D*VIRB(T))
    GO TO(50,50,30,40)K
300 D2=D*D
    D3=D2*D
    D4=D3*D
    N=1
    R=.0820558D0
    M=I
    GAMMA=B(27,M)
    EX=DEXP(D2*GAMMA)
    A(N)=0.0D0
    N=N+1
    A(N)=(D4*D/5.D0)*T**(-2.D0)*(-1.D0)
    N=N+1
    DO 302 I=1,6
    FI=I
    A(N)=(D4/4.D0)*T**(.75D0-FI/4.D0-1.D0)*(.75D0-FI/4.D0)
302 N=N+1
    DO 303 I=1,4
    FI=I
    A(N)=(D3/3.D0)* T**(1.5D0-FI-1.D0)*(1.5D0-FI)
303 N=N+1
    DO 301 I=1,8
    FI=I
    A(N)=(D2/2.D0)*T**(1.5D0-FI/2.D0-1.D0)*(1.5D0-FI/2.D0)
301 N=N+1
    DO 304 I=1,3
    FI=I
    A(N)=(EX/(2.D0*GAMMA))*T**(1.D0-FI-1.D0)*(1.D0-FI)
304 N=N+1
    DO 305 I=1,3
    FI=I
    A(N)=(D2*EX/(2.D0*GAMMA)-EX/(2.D0*GAMMA**2))*
   1T**(1.D0-FI-1.D0)*(1.D0-FI)
305 N=N+1
    N=N-1
    SINT=D*R*(VIRB(T)+T*DBDT(T))
    DO 306 I=1,N
306 SINT=SINT+B(I,M)*A(I)
    N=21
    EX=1.D0
    D2=0.0D0
    DO 310 I=1,3
    FI=I
    A(N)=(EX/(2.D0*GAMMA))*T**(1.D0-FI-1.D0)*(1.D0-FI)
310 N=N+1
    DO 311 I=1,3
    FI=I
    A(N)=(D2*EX/(2.D0*GAMMA)-EX/(2.D0*GAMMA**2))*
   1T**(1.D0-FI-1.D0)*(1.D0-FI)
311 N=N+1
    N=N-1
    DO 312 I=21,N
312 SINT=SINT-B(I,M)*A(I)
```

```
      P=(9.371658D0+5.193043D0*DLOG(T/4.2144D0)-25.31469D0
     1*(SINT+R*DLOG(R*T*D)))
      P=P*4.0026D0
      I=M
      GO TO(50,50,30,40)K
  400 KH=0
      GO TO 9
  413 PP=P
      KH=1
      D2=D*D
      D3=D*D2
      D4=D3*D
      N=1
      R=.0820558D0
      M=I
      GAMMA=B(27,M)
      EX=DEXP(D2*GAMMA)
      A(N)=(D4*D)/5.D0
      N=N+1
      A(N)=(D4*D/5.D0)*(2.D0/T)
      N=N+1
      DO 402 I=1,6
      FI=I
      A(N)=(D4/4.D0)*(T**(.75D0-FI/4.D0)-T**(.75D0-FI/4.D0)
     1*(.75D0-FI/4.D0))
  402 N=N+1
      DO 403 I=1,4
      FI=I
      A(N)=(D3/3.D0)*(T**(1.5D0-FI)-T**(1.5D0-FI)*(1.5D0-FI))
  403 N=N+1
      DO 401 I=1,8
      FI=I
      A(N)=(D2/2.D0)*(T**(1.5D0-FI/2.D0)-T**(1.5D0-FI/2.D0)
     1*(1.5D0-FI/2.D0))
  401 N=N+1
      DO 404 I=1,3
      FI=I
      A(N)=(EX/(2.D0*GAMMA))*(T**(1.D0-FI)-T**(1.D0-FI)*(1.D0-FI))
  404 N=N+1
      DO 405 I=1,3
      FI=I
      A(N)=(D2*EX/(2.D0*GAMMA)-EX/(2.D0*GAMMA**2))
     1*(T**(1.D0-FI)-T**(1.D0-FI)*(1.D0-FI))
  405 N=N+1
      N=N-1
      HINT=R*T*T*D*DBDT(T)   *(-1.D0)
      DO 406 I=1,N
  406 HINT=HINT+B(I,M)*A(I)
      N=21
      D2=0.0D0
      EX=1.D0
      DO 410 I=1,3
      FI=I
      A(N)=(EX/(2.D0*GAMMA))*(T**(1.D0-FI)-T**(1.D0-FI)*(1.D0-FI))
  410 N=N+1
      DO 411 I=1,3
      FI=I
      A(N)=(D2*EX/(2.D0*GAMMA)-EX/(2.D0*GAMMA**2))*(T**(1.D0-FI)
     1-T**(1.D0-FI)*(1.-FI))
  411 N=N+1
      N=N-1
      DO 412 I=21,N
  412 HINT=HINT-B(I,M)*A(I)
      P=21.8228D0+5.193043D0*(T-4.2144D0)+25.31469D0
     1*(HINT+PP/D-R*T)
      P=P*4.0026D0
      I=M
      GO TO(50,50,30,40)K
```

```
500 D2=D*D
    D3=D2*D
    D4=D3*D
    N=1
    R=.0820558D0
    M=I
    GAMMA=B(27,M)
    EX=DEXP(D2*GAMMA)
    SINT=T*D*R*(2.*DBDT(T  )+D2DBDT2(T)*T)
    A(N)=0.0D0
    N=N+1
    A(N)=(D4*D/5.D0)*T**(-2.D0)*(-1.D0)*(-2.D0)
    N=N+1
    DO 502 I=1,6
    FI=I
    A(N)=(D4/4.D0)*T**(.75D0-FI/4.D0-1.D0)
   1*(.75D0-FI/4.D0)*(.75D0-FI/4.D0-1.D0)
502 N=N+1
    DO 503 I=1,4
    FI=I
    A(N)=(D3/3.D0)* T**(1.5D0-FI-1.D0)*(1.5D0-FI)*(1.5D0-FI-1.D0)
503 N=N+1
    DO 501 I=1,8
    FI=I
    A(N)=(D2/2.D0)*T**(1.5D0-FI/2.D0-1.D0)*(1.5D0-FI/2.D0)
   1*(1.5D0-FI/2.D0-1.D0)
501 N=N+1
    DO 504 I=1,3
    FI=I
    A(N)=(EX/(2.D0*GAMMA))*T**(1.D0-FI-1.D0)*(1.D0-FI)
   1*(1.D0-FI-1.D0)
504 N=N+1
    DO 505 I=1,3
    FI=I
    A(N)=(D2*EX/(2.D0*GAMMA)-EX/(2.D0*GAMMA**2))*
   1T**(1.D0-FI-1.D0)*(1.D0-FI)*(1.D0-FI-1.D0)
505 N=N+1
    N=N-1
    DO 506 I=1,N
506 SINT=SINT+B(I,M)*A(I)
    P=SINT
    EX=1.D0
    D2=0
    N=21
    DO 510 I=1,3
    FI=I
    A(N)=(EX/(2.D0*GAMMA))*T**(1.D0-FI-1.D0)*(1.D0-FI)
   1*(1.D0-FI-1.D0)
510 N=N+1
    DO 511 I=1,3
    FI=I
    A(N)=(D2*EX/(2.D0*GAMMA)-EX/(2.D0*GAMMA**2))*
   1T**(1.D0-FI-1.D0)*(1.D0-FI)*(1.D0-FI-1.D0)
511 N=N+1
    N=N-1
    DO 512 I=21,N
512 P=P-B(I,M)*A(I)
    P=5.193043D0*(3.D0/5.D0)*4.0026D0-P*101.3278D0
    I=M
    GO TO(50,50,30,40)K
 20 K=2
    I=3
    T=TT
    D=DD
    GO TO 8
 30 K=3
    GO TO(33,34,35)KK
 33 D=DD
```

```
      T=TT
      KK=2
      IF(DD.GT.17.3987D0)GO TO 40
      I=1
      GO TO 8
   34 PTI=P
      I=3
      KK=3
      T=TT
      D=DD
      GO TO 8
   35 PTIII=P
   38 F=(15.D0-T)/5.D0
      P=F*PTI+(1.D0-F)*PTIII
      IF(KH.LT.1)GO TO 413
      PP=P
      RETURN
   40 IF(K.EQ.3)K1=3
      GO TO(41,42,43,44)K4
   41 K=4
      I=2
      K4=2
      D=DD
      IF(K1.EQ.0)T=TT
      GO TO 8
   42 PIID=P
      D=17.3987D0
      IF(T.LT.5.2014D0)D=SATL(T)*1000.D0/4.0026D0
      K4=3
      GO TO 8
   43 PIIDC=P
      I=1
      K4=4
      GO TO 8
   44 PIDC=P
      P=PIDC+(PIID-PIIDC)
      K4=1
      IF(K1.EQ.3)GO TO 30
      PP=P
      RETURN
   50 PP=P
      RETURN
      END
      DOUBLE PRECISION FUNCTION CP(D,T)
      IMPLICIT REAL*8 (A-H)
      IMPLICIT REAL*8 (O-Z)
      IMPLICIT INTEGER*4(I-N)
      CALL PROPS(DPDD,D,T,2)
      CALL PROPS(DPDT,D,T,3)
      CP=CV(D,T)+(T*(DPDT**2)/((D**2)*DPDD))*101.3278D0
      RETURN
      END
      DOUBLE PRECISIONFUNCTION SOUND(D,T)
      IMPLICIT REAL*8 (A-H)
      IMPLICIT REAL*8 (O-Z)
      IMPLICIT INTEGER*4(I-N)
      CALL PROPS(DPDD,D,T,2)
      SOUND=((CP(D,T)/CV(D,T))*(DPDD*25311.D0))**.5D0
      RETURN
      END
      DOUBLE PRECISION FUNCTION P MELT(TT)
      IMPLICIT REAL*8 (A-H)
      IMPLICIT REAL*8 (O-Z)
      IMPLICIT INTEGER*4(I-N)
      DIMENSION A(5)
      DATA A/33.28D0,-44.156D0,31.799D0,-4.8159D0,.30313D0/
      T=TT
      IF(T.LE.5.2D0)GO TO 7
```

```
      PMELT=-17.80D0+17.31457D0*T**1.555414D0
      PMELT=PMELT*.98066D0/1.01325D0
      RETURN
    7 P=0.0D0
      DO 9 I=1,5
    9 P=P+A(I)*T**(I-1)
      PMELT=P*9.80665D0/10.1325D0
      RETURN
      END
      DOUBLE PRECISION FUNCTION VIRB(T)
      IMPLICIT REAL*8 (A-H)
      IMPLICIT REAL*8 (O-Z)
      IMPLICIT INTEGER*4(I-N)
      DIMENSION A(9)
      DATA A/-5.0815710041D-7,-1.1168680862D-4,1.1652480354D-2,
     1 7.4474587998D-2,-5.3143174768D-1,-9.5759219306D-1,
     2 3.9374414843D0,-5.1370239224D0,2.0804456338D0/
C     COEFFICIENTS FROM PROGRAM 5/28/70-1630
C     THIS SUB PROGRAM CALCULATES THE SECOND VIRIAL COEFFICIENT FOR
C     HELIUM.  THE RANGE IS FROM 2 TO 1500 DEG K.  INPUT IS TEMPERATURE
C     IN DEGREES KELVIN
C     UNITS ARE ATM, DEG KELVIN, AND MOLES/LITER,4/3/69-1253,R.D.MCCARTY
C     REVISED 2/12/70-925
    1 B=0.0D0
      DO 5 I=1,9
      FI=I
    5 B=B+T**(1.5D0-FI/2.D0)*A(I)
      VIRB=B
      RETURN
      END
      DOUBLE PRECISION FUNCTION DBDT (T)
      IMPLICIT REAL*8 (A-H)
      IMPLICIT REAL*8 (O-Z)
      IMPLICIT INTEGER*4(I-N)
      DIMENSION A(9),V(45)
C     THIS SUB PROGRAM CALCULATES THE SECOND VIRIAL COEFFICIENT FOR
C     HELIUM.  THE RANGE IS FROM 2 TO 1500 DEG K.  INPUT IS TEMPERATURE
C     IN DEGREES KELVIN
      DATA A/-5.0815710041D-7,-1.1168680862D-4,1.1652480354D-2,
     1 7.4474587998D-2,-5.3143174768D-1,-9.5759219306D-1,
     2 3.9374414843D0,-5.1370239224D0,2.0804456338D0/
C     UNITS ARE ATM, DEG KELVIN, AND MOLES/LITER,5/28/70-1630,R.D.MCCARTY
    1 B=0.0D0
      DO 5 I=1,9
      FI=I
    5 B=B+T**(.5D0-FI/2.D0)*A(I)*(1.5D0-FI/2.D0)
      DBDT=B
      RETURN
      END
      DOUBLE PRECISION FUNCTION D2DBDT2(T)
      IMPLICIT REAL*8 (A-H)
      IMPLICIT REAL*8 (O-Z)
      IMPLICIT INTEGER*4(I-N)
      DIMENSION A(9)
      DATA A/-5.0815710041D-7,-1.1168680862D-4,1.1652480354D-2,
     1 7.4474587998D-2,-5.3143174768D-1,-9.5759219306D-1,
     2 3.9374414843D0,-5.1370239224D0,2.0804456338D0/
C     THIS SUB PROGRAM CALCULATES THE SECOND VIRIAL COEFFICIENT FOR
C     HELIUM.  THE RANGE IS FROM 2 TO 1500 DEG K.  INPUT IS TEMPERATURE
C     IN DEGREES KELVIN
    1 B=0.0D0
      DO 5 I=1,9
      FI=I
    5 B=B+T**(.5D0-FI/2.D0-1.D0)*(1.5D0-FI/2.D0)*(.5D0-FI/2.D0)*A(I)
      D2DBDT2=B
      RETURN
      END
      DOUBLE PRECISION FUNCTION FINDTV(PP)
```

```
      IMPLICIT REAL*8 (A-H)
      IMPLICIT REAL*8 (O-Z)
      IMPLICIT INTEGER*4(I-N)
      P=PP
      IF(P.LT..842105D0)GO TO 12
      T=5.D0
      PCAL=VPN(T)
      GO TO 13
   12 PCAL=.049737D0
      IF(DABS(P-PCAL)-.0000001D0*PP)11,11,1
    1 T=2.1720D0
   13 DO 10 I=1,50
      DP=DPDTVP(T)
      DEL=(PCAL-P)/DP
      T=T-DEL
      PCAL=VPN(T)
      IF(DABS(P-PCAL)-.0000001D0*P)11,11,2
    2 IF(DABS(DEL)-.0000001D0*T)11,11,10
   10 CONTINUE
      WRITE(*,100)
   11 FINDTV=T
      RETURN
  100 FORMAT(' TEMPERATURE ITTERATION FAILED AT T=',E14.7)
      END
      DOUBLE PRECISION FUNCTION DPDTVP(TT)
      IMPLICIT REAL*8 (A-H)
      IMPLICIT REAL*8 (O-Z)
      IMPLICIT INTEGER*4(I-N)
      DIMENSION C(12),D(14)
      DATA C/-3.9394635287D0,141.27497598D0,-1640.7741565D0
     1,11974.557102D0,-55283.309818D0,
     1166219.56504D0,-325212.82840D0,398843.22750D0,
     2-277718.06992D0,83395.204183D0,0.D0,0.D0/
      DATA D/-49.510540356D0,651.9236417D0,-3707.5430856D0
     1,12880.673491D0,
     1 -30048.545554D0,49532.267436D0,-59337.558548D0,52311.296025D0,
     2-33950.233134D0,16028.674003D0,-5354.1038967D0,1199.0301906D0,
     3 -161.46362959D0,9.8811553386D0/
      P=0.0D0
      T=TT-DELT(TT)
      IF(T-2.1720D0)10,10,1
    1 DO 5 I=1,10
    5 P=P+C(I)*T**(1-I)*(2-I)
      DPDTVP=P*VPN(T)
      RETURN
   10 DO 15 I=1,14
   15 P=P+D(I)*T**(1-I)*(2-I)
      DPDTVP=P*VPN(T)
      RETURN
      END
      DOUBLE PRECISION FUNCTION VPN(TT)
      IMPLICIT REAL*8 (A-H)
      IMPLICIT REAL*8 (O-Z)
      IMPLICIT INTEGER*4(I-N)
      DIMENSION C(12),D(14)
      DATA C/-3.9394635287,141.27497598,-1640.7741565,11974.557102,
     1-55283.309818,166219.56504,-325212.82840,398843.22750,
     2-277718.06992,83395.204183,0.D0,0.D0/
      DATA D/-49.510540356,651.9236417,-3707.5430856,12880.673491,
     1 -30048.545554,49532.267436,-59337.558548,52311.296025,
     2-33950.233134,16028.674003,-5354.1038967,1199.0301906,
     3 -161.46362959,9.8811553386/
      T=TT
      T=T-DELT(T)
      P=0.0D0
      IF(T-2.1720D0)10,10,1
    1 DO 5 I=1,10
    5 P=P+C(I)*T**(2-I)
```

```
      VPN=DEXP(P)/.76D+6
      RETURN
   10 DO 15 I=1,14
   15 P=P+D(I)*T**(2-I)
      VPN=DEXP(P)/.76D+6
      RETURN
      END
      DOUBLE PRECISION FUNCTION DELT(TT)
      IMPLICIT REAL*8 (A-H)
      IMPLICIT REAL*8 (O-Z)
      IMPLICIT INTEGER*4(I-N)
      T=TT
      DELT=.001D0+.002D0*T
      RETURN
      END
      DOUBLE PRECISION FUNCTION SATV(TT)
      IMPLICIT REAL*8 (A-H)
      IMPLICIT REAL*8 (O-Z)
      IMPLICIT INTEGER*4(I-N)
      DIMENSION GV(6)
      DATA GV/-.069267495322D0,-.1292532553D0,.29347470712D0
     1,-.40806658212D0,.35809505624D0,-.11315580397D0/
      DATA DC/.06964D0/
      DATA TC/5.2014D0/
      T=TT
      DCAL=DC
      R=(1.D0/TC)
      DO 1 I=1,6
      FI=I
    1 DCAL=DCAL+GV(I)*R**(FI/3.D0)
      SATV=DCAL
      RETURN
      END
      DOUBLE PRECISION FUNCTION SATL(TT)
      IMPLICIT REAL*8 (A-H)
      IMPLICIT REAL*8 (O-Z)
      IMPLICIT INTEGER*4(I-N)
      DIMENSION GL(9)
      DATA GL/.12874326484D0,-.43128217346D0,1.7851911824D0
     1,-3.3509624489D0,3.0344215824D0,-1.0981289602D0,0.D0,0.D0,0.D0/
      DATA DC/.06964D0/
      DATA TC/5.2014D0/
      T=TT
      DCAL=DC
      R=(1.D0-T/TC)
      DO 2 I=1,6
      FI=I
    2 DCAL=DCAL+GL(I)*R**(FI/3.D0)
      SATL=DCAL
      RETURN
      END
      DOUBLE PRECISION FUNCTION SURFTEN(T)
      IMPLICIT REAL*8 (A-H)
      IMPLICIT REAL*8 (O-Z)
      IMPLICIT INTEGER*4(I-N)
      SURFTEN=.5308D0*(1.-T/5.2014D0)
      RETURN
      END
      DOUBLE PRECISION FUNCTION R INDEX(D,W)
      IMPLICIT REAL*8 (A-H)
      IMPLICIT REAL*8 (O-Z)
      IMPLICIT INTEGER*4(I-N)
      DD=D*4.0026D0/1000.D0
      ALG=0.123396D0-0.0014*DD+33701.617944/D0W**2-12325284955.D0/W**4
      FAC=ALG*DD/0.95555D0
      R=((2.D0*FAC+1.D0)/(FAC-1.D0))
      IF(R.LT.0.0D0)R=R*(-1.)
      R=R**(.5D0)
```

```
      RINDEX=R
      RETURN
      END
      DOUBLE PRECISION FUNCTION TMELT(PP)
      IMPLICIT REAL*8 (A-H)
      IMPLICIT REAL*8 (O-Z)
      IMPLICIT INTEGER*4(I-N)
      P=PP*1.01325D0/.98066D0
      IF(P-17.80D0.LT.0.0D0)GO TO 1
      TMELT=((P-17.80D0)/17.3145D0)**(1./1.555414D0)
      RETURN
    1 TMELT=2.D0
      RETURN
      END
      DOUBLE PRECISION FUNCTION FDIEL(D)
      IMPLICIT REAL*8 (A-H)
      IMPLICIT REAL*8 (O-Z)
      IMPLICIT INTEGER*4(I-N)
      DD=D*4.0026D0/1000.D0
      ALPHA=.123396D0-.0014D0*DD
      ALPHA=ALPHA*DD *1.04652D0
      EPS=(1.D0+2.D0*ALPHA)/(1.D0-ALPHA)
      FDIEL=EPS
      RETURN
      END
      DOUBLE PRECISION FUNCTION THERM(DD,TT)
      IMPLICIT REAL*8 (A-H)
      IMPLICIT REAL*8 (O-Z)
      IMPLICIT INTEGER*4(I-N)
C      HELIUM
C     THIS ROUTINE CALCULTATES THERMAL CONDUCTIVITY AND VISCOSITY
C     FOR AN INPUT OF DEGREES KELVIN AND DENSITY IN MOLES PER LITER
C     THE RANGE OF TEMPERATURE IS FROM 2 TO 2000 K
C     FOR TEMPERATURES BELOW 300 K FORMULAS OFD VINCE ARP AND GE STEWARD
C     ARE USED, FOR TEMPERATURES ABOVE 300 THE DILUTE GAS OF A CRITICAL
C     COMPILATION FROM ENGLAND IS USED FOR BOTH VISCOSITY AND
C     THERMAL CONDUCTIVITY AND THE EXCESS FUNCTIONS FROM THE ROUTINES BY
C     ARP AND STEWART)   THE EXCESS FUNCTIONS ARE CALCULATED FOR TEMPS
C     ABOVE 300 K WITH THE TEMPERATURE DEPENDENCE HELD AT 300 K
C     FOR TEMPS BELOW 300 K TO 100 K THE VISCOSITY EXCESS IS CALC
C     FROM STEWARTS ROUTINE BUT THE DILUTE GAS VALUES ARE TAKEN FROM
C     THE ENGLISH CORRELATION FOR TEMPS BETWEEN 100 AND    110 T
C     DILUTE GAS  CALCULATION IS AVARAGED
    1 D=DD
      T=TT
      RHO=D*4.0026D-3
      IF(T.LT.300.D0)GO TO 5
      THO30=VISCX(300.D0)*.00781736D0
      THO300=CONZ(300.D0)
      DEL300=DELC(300.D0,RHO)
      THO=VISCX(T)*.00781736D0+THO300-THO30
      THE=THO300*DEL300-THO300
      THERM=THO+THE
      RETURN
    5 THERM=CONZ(T)*DELC(T,RHO)+CRITIC(T,RHO)
C     OUTPUT IN MW/CM.K
      RETURN
      END
      DOUBLE PRECISION FUNCTION VISC(DD,TT)
      IMPLICIT REAL*8 (A-H)
      IMPLICIT REAL*8 (O-Z)
      IMPLICIT INTEGER*4(I-N)
      D=DD
      T=TT
      IF(T.LT.100.D0)GO TO 10
      IF(T.LT.300.D0)GO TO 8
      ETAO=VISCX(T)
      ETO30=VISCX(300.D0)
```

```
      ETO300=VISCDT( 0.0D0, 300.D0)
      ETE300=VISCDT( D, 300.D0)-ETO300
      VISC=ETAO+ETE300
C  OUTPUT UNITS ARE MICROPOISE
      RETURN
    8 IF( T.LT.110.D0)GO TO 9
      ETAO=VISCX( T)
      ETEB=VISCDT( D, T)-VISCDT( 0.0D0, T)
      VISC=ETAO+ETEB
      RETURN
    9 ETA1=VISCDT( 0.0D0, 100.D0)
      ETA2=VISCX( 110.D0)
      ETAO=ETA1+( ETA2-ETA1)*( T-100.D0)/10.D0
      VISC=ETAO+VISCDT( D, T)-VISCDT( 0.0D0, T)
      RETURN
   10 VISC=VISCDT( D, T)
      RETURN
      END
      DOUBLE PRECISION FUNCTION VISCX(  T )
      IMPLICIT REAL*8 ( A-H)
      IMPLICIT REAL*8 ( O-Z)
      IMPLICIT INTEGER*4( I-N)
      VISCX=196.D0*T**.71938D0*DEXP(  12.451D0/T-295.67D0/T/T-4.1249D0)
      RETURN
      END
      DOUBLE PRECISION FUNCTION DELC( TEMP,  RHO)
      IMPLICIT REAL*8 ( A-H)
      IMPLICIT REAL*8 ( O-Z)
      IMPLICIT INTEGER*4( I-N)
C     K=KZERO*EXPF( B( T)*RHO + C( T)*RHO**2)
C      THIS PROGRAM RETURNS EXPF( B( T)*RHO + C( T)*RHO**2)
    1 BB=DLOG( TEMP)
      CC=1.D0/TEMP
      BETTY=4.7470660612D0-5.3641468153D0*BB+3.4639703698D0*BB**2
     2-1.0702455443D0*BB**3+0.1571349306D0*BB**4-.00892140047D0*BB**5
      B=DEXP( BETTY)
      C=2.2109006708D0+187.74174808D0*CC-1281.0947055D0*CC*CC
     3+3645.2393216D0*CC**3-3986.6937948D0*CC**4
      DELC=DEXP( B*RHO+C*RHO*RHO)
      RETURN
      END
      DOUBLE PRECISION FUNCTION CONZ( TEMP)
      IMPLICIT REAL*8 ( A-H)
      IMPLICIT REAL*8 ( O-Z)
      IMPLICIT INTEGER*4( I-N)
C     KZERO IN MILLIWATTS/CM-K,  T IN KELVIN9  22 JUNE 71.
    1 ANNE=DLOG( TEMP)
      PAT=-4.3611622157D0+1.9250159286D0*ANNE-0.52544120165D0*ANNE**2
     1+.090045763885D0*ANNE**3-.0054773874708D0*ANNE**4
      CONZ=DEXP( PAT)
      RETURN
      END
      DOUBLE PRECISION FUNCTION VISCDT( DGC, T)
      IMPLICIT REAL*8 ( A-H)
      IMPLICIT REAL*8 ( O-Z)
      IMPLICIT INTEGER*4( I-N)
C     W. G. STEWARD, S DATA   23 JUNE 71
C  INPUT UNITS ARE KELVIN AND MOL/LITER
C  OUTPUT UNITS ARE MICROPOISE
      TL=DLOG( T)
      R=DGC*4.0026D0/1000.D0
      ANNE=-0.135311743D0/TL+1.00347841D0+1.20654649D0*TL
     1-0.149564551D0*TL*TL+0.0125208416D0*TL**3
      BETTY=R*( -47.5295259D0/TL+87.6799309D0-42.0741589D0*TL
     1+8.33128289D0*TL*TL-0.589252385D0*TL**3)
      CAROL=R*R*( 547.309267D0/TL-904.870586D0+431.404928D0*TL
     1-81.4504854D0*TL*TL+5.37008433D0*TL**3)
      DAGMAR=R**3*( -1684.39324D0/TL+3331.08630D0-1632.19172D0*TL
```

```
     1+308.804413D0*TL*TL-20.2936367D0*TL**3)
      VISCDT=DEXP(ANNE+ BETTY+ CAROL+ DAGMAR)
      RETURN
      END
      DOUBLE PRECISION FUNCTION CRITIC(TEMP,RHO)
      IMPLICIT REAL*8 (A-H)
      IMPLICIT REAL*8 (O-Z)
      IMPLICIT INTEGER*4(I-N)
C     CRITICAL ANOMALY FOR HE THERM. CON., SCALED FROM H-2
C     T IN KELVIN, REQUIRES DENSITY IN GRAMS/CC AND CP IN JOULES/MOLE
C     THIS DECK OF 18 SEPT 70, I HAVE USED MCCARTY"S HE DECKS OF 7/18/70
    4 T=TEMP
    5 DML=RHO/0.0040026D0
    6 IF(T .GE. 11.83D0) GO TO 11
      IF(RHO.GT.0.12D0) GO TO 11
    7 CP1=CP(DML,T)
    8 CP2=CP(DML,11.83D0)
    9 CRITIC=0.0026D0*(CP1-CP2)/4.0026D0
   10 IF(CRITIC)11,12,12
   11 CRITIC=0.0D0
   12 RETURN
      END
```

HELIUM.COF

```
-.1509686261900E-06
 .6464089890400E-06
 .4136235736700E-04
-.3791019035300E-03
 .1380645404900E-02
-.2508541205800E-02
 .2369756039800E-02
-.9572646106600E-03
 .3740593182800E-04
-.6410322033300E-03
 .1857936617700E-02
 .7400798660600E-03
 .1479256814800E-03
-.3253135547700E-02
 .1951873928600E-01
-.1057181713500E+00
 .3316494444900E+00
-.5113002253500E+00
 .3994000490600E+00
-.1555524447100E+00
 .4906264031000E-02
-.2614800437700E-01
 .3422168554500E-01
 .5415966262200E-05
-.1068780677700E-04
-.8948465186900E-05
-.2500000000000E-02
-.4228745462600E-07
 .4452935441300E-06
-.1024615095400E-04
 .8525460895600E-04
-.2516306925500E-03
 .3287770928500E-03
-.1060195758000E-03
-.1068773807400E-03
```

```
 -.3212095063200E-04
  .1415901897000E-03
  .1472563070100E-02
 -.2618354941000E-02
  .2046150111700E-04
  .1274699628800E-02
 -.2027292958300E-01
  .7464803661500E-01
 -.1721796652100E+00
  .5105343973800E+00
 -.4017820269700E+00
  .2682986463200E+00
  .7906601204000E-02
 -.8939348565600E-01
 -.1507658005300E+00
  .2688249432700E-05
 -.3379431683500E-04
 -.2449595119500E-04
 -.5000000000000E-03
 -.1480219534800E-07
  .4172179111900E-06
 -.2332655327100E-06
  .4085511088000E-06
  .1090056796400E-04
 -.5006095277500E-04
  .1131276504300E-03
 -.1253984328700E-03
  .1966138068800E-05
  .1712293266600E-03
  .2305100056300E-03
 -.9656473910000E-03
 -.3602773529200E-04
  .1607994655500E-02
 -.2744176361500E-01
  .1473950695700E+00
 -.4355934483800E+00
  .1344795607800E+01
 -.1704037512500E+01
  .9026267404000E+00
  .5687564411100E-02
 -.1443814662500E+00
  .3376887485100E-02
  .1075420121800E-05
 -.4526462230800E-04
  .3859738886400E-04
 -.5000000000000E-03
1500.              2.17D0    100.   5.2014   17.399   .22746
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5. AUTHOR(S)

Robert D. McCarty

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10. SUPPLEMENTARY NOTES

☐ Document describes a computer program; SF-185, FIPS Software Summary, is attached.

11. ABSTRACT (A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here)

The thermophysical and transport properties of selected fluids have been programmed in FORTRAN 77 which is available for micro computers. The input variables are any two of P, ρ, T (pressure, density, and temperature) in the single phase regions, and either P or T for the saturated liquid or vapor states. The output is pressure, density, temperature, internal energy, enthalpy, entropy, specific heat capacities (C_p and C_v), speed of sound and, in most cases, viscosity, thermal conductivity, and dielectric constant.

The fluids included are: helium, hydrogen, nitrogen, oxygen, argon, nitrogen trifluoride, methane, ethylene, ethane, propane, iso- and normal butane. The programs give properties in both the liquid and vapor states over a wide range of temperature and pressure. Copies of the program may be obtained from the Office of Standard Reference Data, Room A320, Physics Building, National Bureau of Standards, Gaithersburg, MD 20899.

12. KEY WORDS (Six to twelve entries; alphabetical order; capitalize only proper names; and separate key words by semicolons)

argon; computer programs; density; dielectric constant; enthalpy; entropy; equation of state; ethane; ethylene; heat capacity; helium; hydrogen; internal energy; isobutane; methane; nitrogen; nitrogen trifluoride; normal butane; oxygen; pressure; speed of sound; temperature; thermal conductivity; viscosity.

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